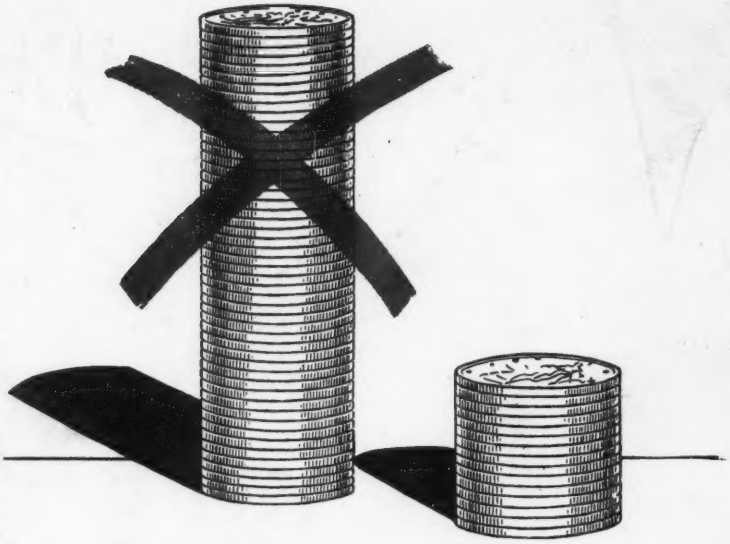
Corrosion

June 1946



Reduction in Capital Investment

An Important Factor in

The Economics of Cathodic Protection

CORROSION-PROOF pipelines are now being built, and built economically by using modern protection systems. Because Coal-tar Enamels provide stable insulation to steel pipe, fewer Cathodic Protection installations are needed, thus reducing the capital investment and requiring a minimum amount of electrical current, maintenance and amortization annually.

With the use of Coal-tar Enamel, applied properly by modern methods of application in the mills or in the field, as much as 60 per cent, or more, can be saved in the cost of the complementary Cathodic Protection.

Barrett Coal-tar Enamel, which possesses high dielectric strength, provides constant, uniform and long-lasting stable underground insulation, and retains electrical stability over a long period of years and under varying conditions of soil and climate!

The use of Barrett Coal-tar Enamel assures the economy of your investment in Cathodic Protection.

THE BARRETT DIVISION
ALLIED CHEMICAL & DYE CORPORATION
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FIELD SERVICE: *The Barrett Pipeline Service Department and staff of Field Service men are equipped to provide both technical and on-the-job assistance in the use of Barrett Enamel.*

Barrett
COAL-TAR
ENAMEL

Installed on many product pipe lines ...ALCO Clamp Ring basic operating advantage

Development of the ALCO Clamp Ring opened the way to important improvements in pipe line filter design. Because it permitted the full cross-sectional area of the shell to be useful, ALCO engineers were enabled to design a filter in which a separate, easily removable filter basket could be centrally located in the shell. Because the filter basket could be so located, the space between it and the shell is available for proper dispersal of the incoming product over the filter surface. Because the filter basket is readily removable, the filter medium can be quickly and easily discharged and renewed.

ALCO *Filter Cartridges*

For service in ALCO Pipe Line Filters, ALCO has developed a special filter cartridge of assured uniform density. These efficient, easy-to-handle cartridges eliminate the nuisance of handling, shredding and packing baled filtering material. ALCO supplies a special device for loading and unloading these cartridges.

ALCO *Pipe Line Filters Installed on "Little Big Inch," "Canol," and other pipe lines*

ALCO Pipe Line Filters are on the "Little Big Inch" (Baytown, Texas, to Bayonne, N. J.), the Canol Pipe Line (Fort Norman to Whitehorse, Canada) and others. Hundreds of these ALCO units are in service. **Protect your pumps. Reduce maintenance costs. Use ALCO Pipe Line Filters to eliminate gritty material.** Complete description and schematic drawings show design and operation in *ALCO Bulletin 1033.* Copy sent promptly on request.

*Patent Pending

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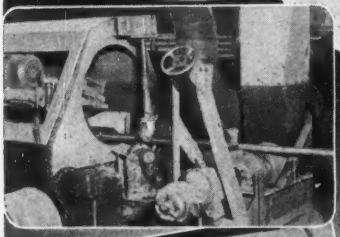
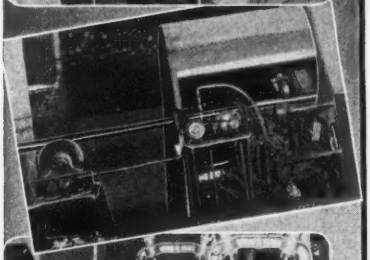
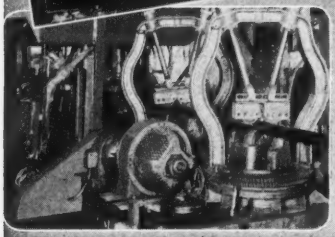
Sound Factory methods assure long service life to HILL HUBBELL PIPE PROTECTION





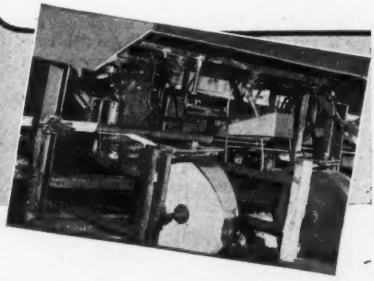


MACHINE CLEANED PRIMED COATED AND WRAPPED STEEL PIPE

4 progressive steps in FACTORY applied Steel Pipe Processing are illustrated in the accompanying factory scenes.

The pipe is conveyed, cleaned—primed — coated — wrapped and loaded all indoors, by modern mechanical methods; each operation under absolute control.

HILL, HUBBELL Steel Pipe Protection keeps your pipe lines always working.



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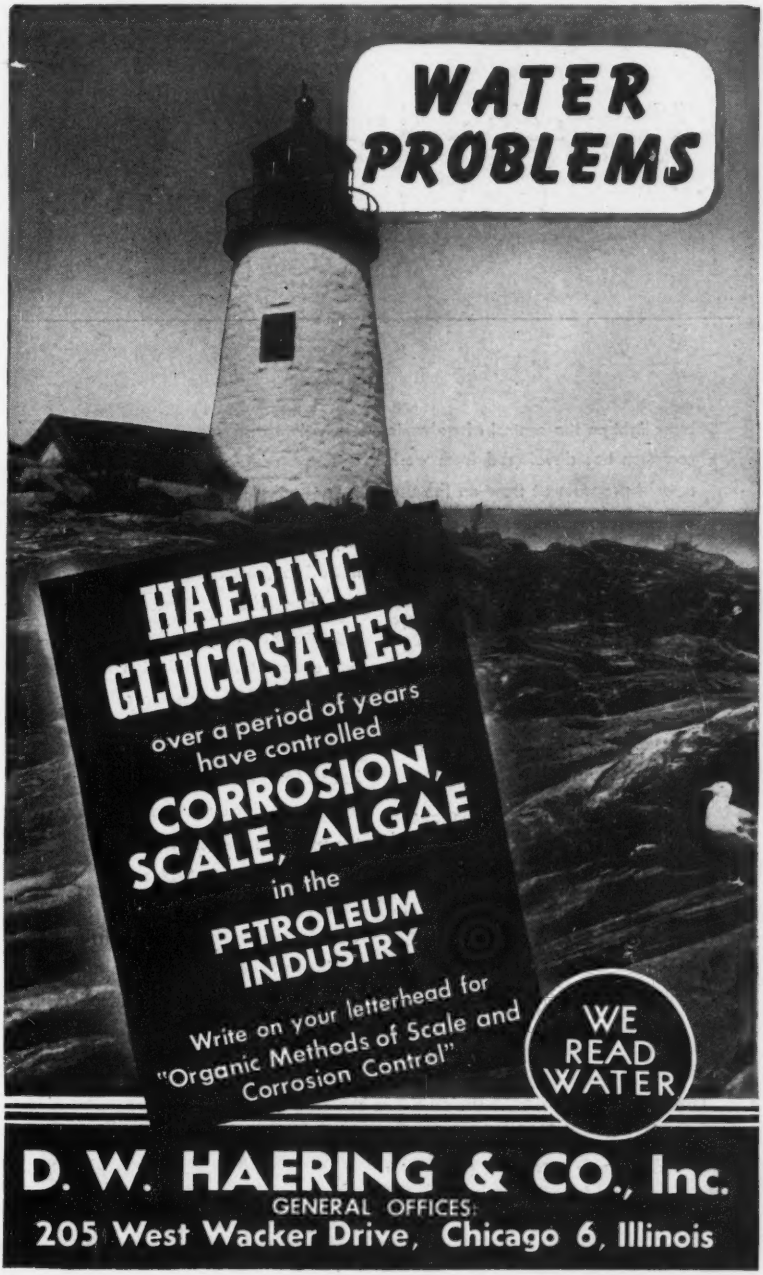
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Magnesium Anodes for Cathodic Protection

New light on the control of galvanic corrosion has developed from work now in progress at Dow on the use of magnesium anodes for cathodic protection.

The Dow research program to date covers a long series of laboratory and field tests and has produced some very interesting data. As rapidly as this information can be prepared for publication, it will be made available.

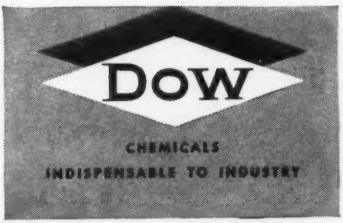
Tests on pipe lines, steel foundations, underground tanks, and metals in contact with sea water indicate that galvanic corrosion can be materially reduced by the use of expendable external anodes of magnesium. Because of its high electro chemical equivalent and its high driving voltage, magnesium is a logical material for this purpose.

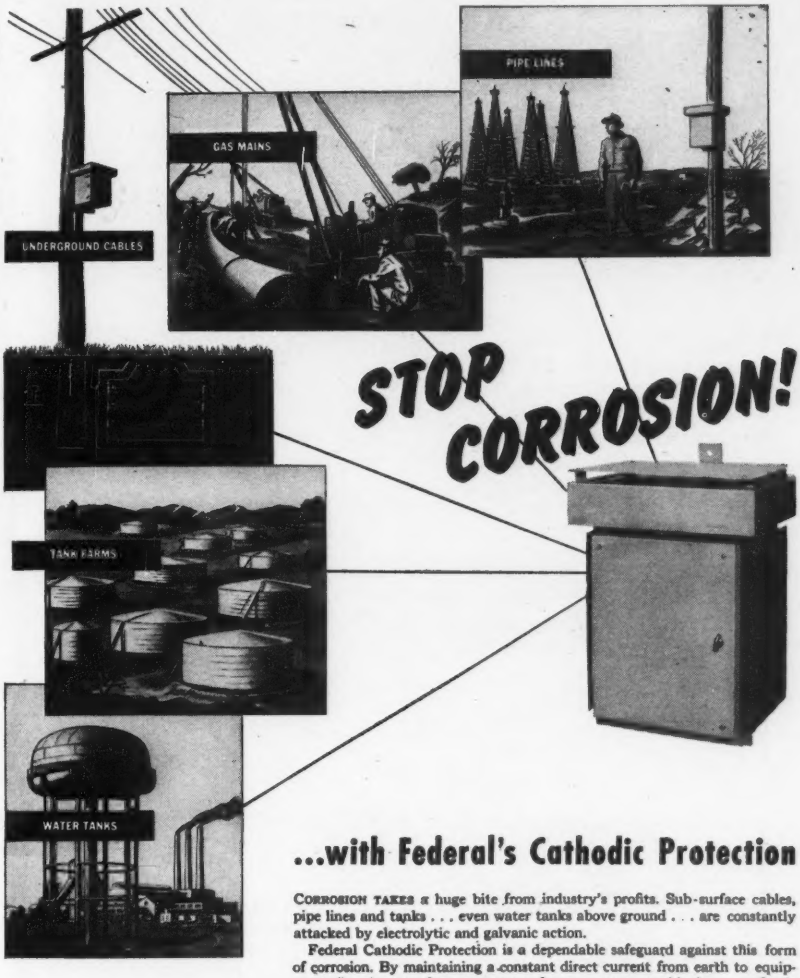
Replaceable magnesium anodes, connected to structures to be protected, show marked effectiveness in supplying the current demanded by cathodic areas, correspondingly reducing the rate at which anodic areas on the structures are dissolved.

Results to date indicate the potential usefulness of magnesium anodes in the practical control of galvanic corrosion on an industrial scale. Dow invites industrial concerns and individuals confronted with corrosion problems to contact the nearest Dow office for literature or consultation.

MAGNESIUM DIVISION
THE DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN

New York • Boston • Philadelphia • Washington
Cleveland • Detroit • Chicago • St. Louis • Houston
San Francisco • Los Angeles • Seattle • Tulsa





...with Federal's Cathodic Protection

CORROSION TAKES a huge bite from industry's profits. Sub-surface cables, pipe lines and tanks . . . even water tanks above ground . . . are constantly attacked by electrolytic and galvanic action.

Federal Cathodic Protection is a dependable safeguard against this form of corrosion. By maintaining a constant direct current from earth to equipment (in above-surface structures, from water to tank's inner surface), Federal Selenium Rectifiers counteract destructive currents . . . and stop disintegration of metal surfaces.

These units operate from any standard AC supply. They do their work efficiently, silently . . . with no moving parts to wear, or require maintenance.

Learn how Federal selenium rectifying units can be put to work to guard your own installations. Write today for a copy of "Cathodic Protection and Applications of Selenium Rectifiers".

Federal Telephone and Radio Corporation

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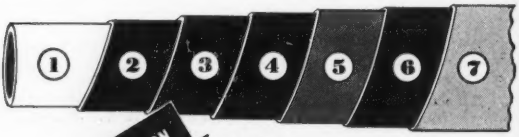
PIPE COATING AND WRAPPING SPECIFICATIONS

Easy as A-B-SEE!

To simplify ordering pipe coating and wrapping, Pipe Line Service Corporation offers you the easiest specifications you could ask for. You indicate either "Specification A" or "Specification B" together with the coating material desired and PLS does the rest. When you consider that you can get any type of protection you want, it's just good business to let Pipe Line Service assume the complete responsibility for the finished job.

SPECIFICATION "A"

INCLUDES
(1) Mechanical cleaning.
*(2) Mechanical priming with desired primer.
(3) Hot application of desired coating.
(4) Hot application of desired coating.
(5) One spiral wrapping of desired wrapping material.
(6) One spiral wrapping of heavy kraft paper.



SPECIFICATION "B"

INCLUDES
(1) Mechanical cleaning.
*(2) Mechanical priming with desired primer.
(3) Hot application of desired coating.
(4) Hot application of desired coating.
(5) One spiral wrapping of desired wrapping material.
(6) Hot application of desired coating.
(7) One spiral wrapping of heavy kraft paper.

PROTECTIVE COATING MATERIALS AVAILABLE ON ABOVE SPECIFICATIONS

- Asphalts
- Barrett Millwrap Enamel
- Barrett Pipe Line Enamel
- Barrett Waterworks Enamel
- Bitumastic Regular Enamel
- Bitumastic 70-B Enamel
- Bitumastic XXH Enamel
- Ennjay Enamel
- *No-Ox-Id
- Reilly Filled Pitch Enamel
- Reilly No. 230 Enamel

*Primer not required with No-Ox-Id coatings.

PIPE LINE SERVICE CORP. SERVICE EQUIPMENT MATERIALS FRANKLIN PARK, ILL.

OTHER MATERIALS AND SPECIFICATIONS ON REQUEST

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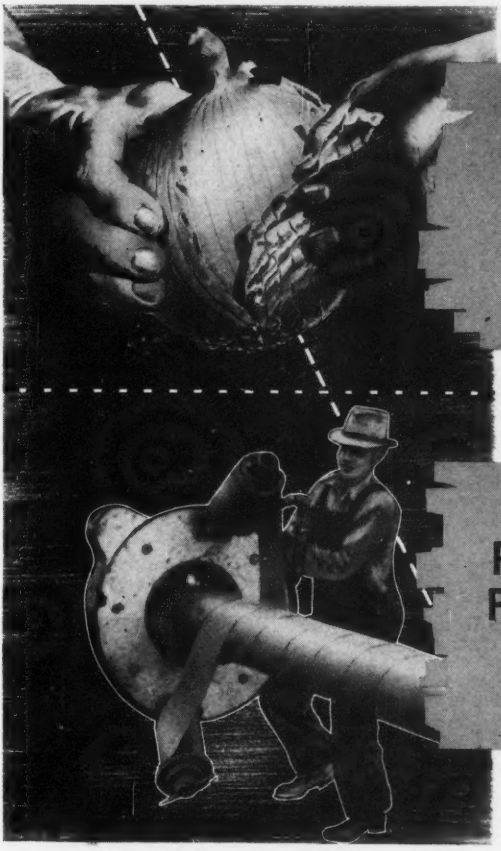
Pioneers in Steel Pipe Protection

General Office and Plant — FRANKLIN PARK, ILL.

Plants at: GLENWILLARD, PA. • LONGVIEW, TEX. • CORPUS CHRISTI, TEX.



NATURE PROTECTS CROPS
Against Soil Contamination

MAN PROTECTS PIPELINES
Against Soil Corrosion

Nature develops protective coatings for her products. The humble onion is an example. As the onion bulb is maturing, the upper part of the "scales", or leaves, dry, shrivel, and twist tightly together.

Inner portions are thus protected from shearing action of the soil, from discoloration, from moisture.

Man also uses similar protective methods by applying NO-OX-IDized wrapper, which envelopes pipe lines laid through highly corrosive soils. Used with NO-OX-ID, the original rust preventive compound, NO-OX-IDized wrapper resists soil action, reinforces the coating, and bars corrosion. Write for details.

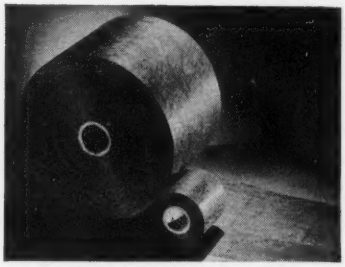
The ORIGINAL RUST PREVENTIVE

Dearborn Chemical Company
Dept. CO, 310 S. Michigan Ave., Chicago 4, Ill.
New York • Los Angeles • Toronto

extra years of corrosion protection

Fiberglas Underground Pipe Wrap is helping provide a more efficient and more economical solution to one of the industry's oldest and most costly problems—*protection against corrosion of underground pipe.*

As used on underground lines in many parts of the country, Fiberglas Underground Pipe Wrap is a thin, porous mat of long, fine glass fibers. The mat is noncorrosive and does not cause corrosion in contact with metals. It is acid- and heat-resistant—provides protection against moisture contact and insulation against galvanic currents and greatly reduces cold flow of the protective coating. The mat has adequate strength for high-speed applications at standard machine tensions. Its porosity allows air or vapors to escape, thus retaining a continuous film or coating. And its large surface area gives it a high pickup factor, permits more coating or impregnant to be used in a given thickness of wrap.



Fiberglas Underground Pipe Wrap is furnished in minimum length rolls of 450 ft., in standard widths from 4″ to 24″.

Write for the new booklet describing Fiberglas Underground Pipe Wrap—for corrosion protection on all types of new or reconditioned lines. Owens-Corning Fiberglas Corporation, Dept. 958, Toledo 1, Ohio. Branches in principal cities.

In Canada, Fiberglas Canada Ltd., Oshawa, Ontario.

OWENS-CORNING

FIBERGLAS

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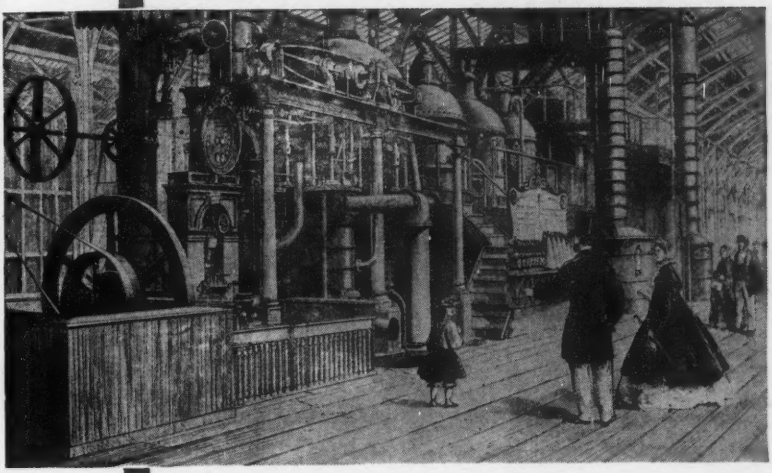
PIPE WRAP



Famous Facts

Wide interest was attracted by the elaborate Sugar Refining Apparatus displayed by Messrs. Caile and Company at the London International Exhibition in 1862. Such exhibits helped immeasurably to raise the standard of living through the promotion of the industrial arts.

At the same time, Bitumastic Enamel — the first product of its kind — was attracting notice for its performance in preventing corrosion of the internal surfaces of steel ships. It has continued to display its superiority as a protective coating for pipe lines and other underground and underwater metal surfaces in industry throughout the world.

Impervious to water and chemicals present in highly corrosive soil, Bitumastic Enamel gives maximum protection to oil, gas and gasoline pipe lines. Because of its high viscosity, it provides a thick coating. It is further characterized by good adhesion and great resistance to cracking and soil stress.

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CORPORATION

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FOR CATHODIC PROTECTION OF PIPE LINES

•

THE NEW JERSEY ZINC COMPANY'S HIGH QUALITY MIX NO. 1 ROLLED ZINC PLATES

THE NEW JERSEY ZINC COMPANY

PRODUCTS DISTRIBUTED BY

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One of Five 50-foot "Percolators" lined with WELDED EVERDUR SHEETS

One of the five large "percolators." A total of 66,000 lb. of Everdur sheet and tube was used in fabricating the complete plant. Note the slotted Everdur screens welded into conical section.

THIS LARGE VESSEL is part of a plant designed and engineered by The Vulcan Copper and Supply Company, Cincinnati, Ohio, to produce 190 proof ethyl alcohol from wood waste. Among the numerous equipment items especially designed for this plant were five steel percolators 96" I.D. x 50'3" high, which were fabricated by the Southwest Welding and Mfg. Company of Alhambra, California. Everdur* Metal, because of its high strength, corrosion resistance and weldability was used for the linings, in sheets .134" thick.

Welds in the Everdur lining had to develop approximately 85% tensile strength of the annealed sheets, with elongation of at least 60% on free bend test. With the assistance of a welding engineer from The American Brass Company, a carbon arc welding procedure, using Everdur rods, was established, developing 98.5% tensile strength and 64% elongation. Two operators thus instructed were qualified at 87.5% and 95% tensile strength, and 72% and 76% elongation.

This method of design and construction resulted in an increased volume of wood waste treated in each charge which, together with various operational changes, promises a daily output *several times greater than* the previous process.

*Reg. U. S. Pat. Off. 46195A

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THE AMERICAN BRASS COMPANY
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Subsidiary of Anaconda Copper Mining Company
In Canada: ANACONDA AMERICAN BRASS LTD., *New Toronto, Ont.*

CORROSION INFORMATION

. . . available to all

IN working out the design of equipment, engineers can proceed on the basis of well-established and consistent *mechanical* properties of their materials.

However, where corrosive environments are to be encountered in use, an uncertainty often appears as to how these materials will perform. For corrosion resistance is not a *fixed* property—but, rather, one that varies greatly with media and operating conditions.

To help you eliminate—*or minimize*—this uncertainty of selection, The International Nickel Company offers its experience, facilities and accumulated data.

The corrosion engineering research—started by INCO over 38 years ago—has helped put metal selection upon a scientific footing. Laboratory studies, plant tests, outdoor and marine tests have yielded a fund of corrosion data to guide designers and buyers of equipment.

INCO originally undertook this research because one of the principal markets for Nickel is in alloys designed primarily to resist corrosion. Throughout the years, the guiding aim of the program was *to use Nickel Alloys where they belonged . . . and to best advantage.*

Carrying out this aim made it necessary not only to establish what Nickel Alloys could do, but also to discover how they would perform relative to other materials. Guided by this information, INCO's corrosion engineers can make recommendations for Nickel Alloys in specific applications.

INCO corrosion engineering research can be put to work for you in three ways:

By applying to your particular problem the information recorded on over 30,000 corrosion data sheets.

By carrying out specially-developed tests in your own plant.

By undertaking studies of general corrosion problems at INCO *Laboratories and* INCO *Field Test Stations.*

INCO corrosion engineers will make INCO's corrosion information as readily available to you as if it were in your own files.

INCO
TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

Succeeding advertisements will discuss in detail the corrosion research activities carried on by The International Nickel Company

This new J-M machine DOUBLE COATS and DOUBLE WRAPS in one operation!

This machine was especially developed for J-M by Crutcher-Rolfs-Cummings of Houston.

Here's the way to get "plus" protection for your pipelines in double-quick time!

THIS ingenious J-M machine alternately applies *two* layers of Johns-Manville Asbestos Felts and *two* coats of enamel to give protection against severe corrosive conditions.

Pioneers in the manufacture and application of asbestos wrappings . . . Johns-Manville has gone a step further with this new machine.

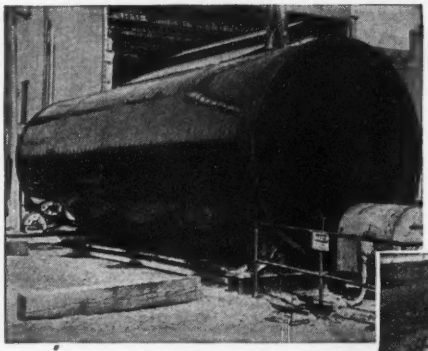
The J-M Coating and Wrapping Machine can save time and money for you, just as J-M Asbestos Pipeline Felts safeguard the enamel on your lines against soil stress and distortion. For further information, write Johns-Manville, 22 East 40th Street, New York 16, N. Y.

JOHNS-MANVILLE JM PRODUCTS

Johns-Manville *Asbestos* Pipeline Felts

STOPS CORROSION

UNDER GROUND, UNDER WATER, OR ABOVE GROUND—Under All Conditions of Soil and Climate



● Reilly Coal Tar Coatings stop corrosion before it has a chance to get started. As a coating on conduits and pipe lines, Reilly Enamel seals and insulates the steel against corrosive agencies of all kinds. As a lining on water conduits and tanks, Reilly Enamel not only stops corrosion, but also prevents incrustation and tuberculation.

Reilly Enamel is so regulated in its properties that it will withstand temperatures as high as 160°F without flow or sag, and as low as minus 20°F without cracking or chipping.

Reilly Cold Application Coatings provide similar protection against corrosion on tanks, towers, stacks, metal buildings, structural steel and other metal construction, whether serving above ground, under ground or under water.

This booklet, describing Reilly Protective Coatings for Metal, Stone, Brick, Cement and Wood Surfaces, will be sent on request.

Reilly protective coatings

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Corrosion

An Official Publication of the
NATIONAL ASSOCIATION OF
CORROSION ENGINEERS

Volume II JUNE, 1946 Number 2

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NATIONAL ASSOCIATION OF CORROSION ENGINEERS

ELTON STERRETT, Executive Secretary

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The Effectiveness of Paint in Suppressing Galvanic Corrosion

By G. W. Seagren
Senior Fellow, Stoner-Mudge, Inc., Multiple Fellowship on Protective Coatings, Mellon Institute, Pittsburgh, Pa.

G. H. Young
Executive Assistant to the Director, Mellon Institute, Pittsburgh, Pa.

and

F. L. LaQue
Development and Research Division, The International Nickel Company, Inc., New York, N. Y.

1. Introduction

THE LABORATORY evaluation of paint as a protective coating is usually made with test panels of a single metal, such as iron. However, paint systems are frequently used on structures which may consist of a combination of metals, such as iron and copper, brass or bronze. It is well known that, when two different metals are connected in the same structure in an aqueous environment, one of the metals corrodes at a higher rate and the other at a lower rate than either would corrode normally, if they were not coupled. This is galvanic corrosion.

The degree of acceleration or deceleration of corrosion depends upon several factors, one of which is the relative position of the two metals in the familiar electrochemical series. Steel and copper or copper alloys are common metals which are often used together in diverse structures. When these structures are exposed in aqueous environments, such as sea water, accelerated corrosion of the steel portions is almost certain to take place.

A common example of this condition is found on ships' bottoms. The ship's propellers are usually made of bronze; the hull, rudder and struts, of steel. Accelerated corrosion oc-

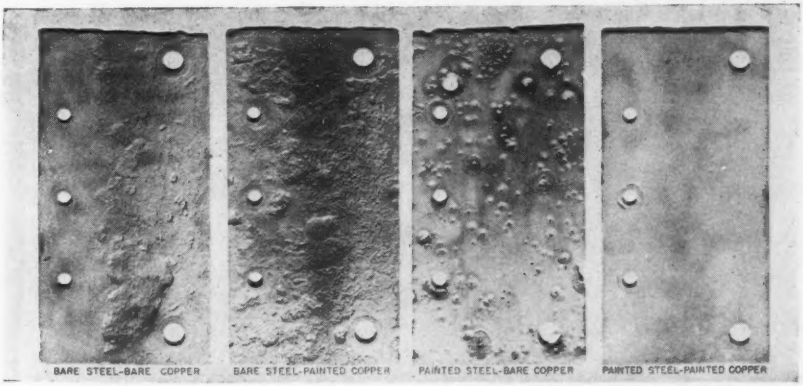

Figure 1—Copper-Steel couple test. Six months complete immersion at Kure Beach, N. C. Paint System A, Steel panels after cleaning.

curs on those steel areas adjacent to the bronze parts. Examples of accelerated corrosion caused by dissimilar metals occur also in steel pipelines which are joined by brass or bronze couplings, and in steel hot-water tanks to which copper tubing is connected. In these cases, because the steel is the corroding metal and the copper or copper alloy does not corrode, it is common practice (and perhaps logical) to paint the surface which is to be protected from corrosion, i.e., the steel.

To determine the real effect of painting on galvanic corrosion, a number of experiments were made, using the International Nickel Company's test facilities at Kure Beach, North Carolina.

Galvanic corrosion can occur in all aqueous media, but the degree to which it occurs is largely dependent upon the conductivity of the environment. Accordingly, marine exposure was selected for our test panels, because galvanic corrosion is most severe in salt water, which has high conductivity.

SECTION I—EFFECT OF PAINTING ANODE AREAS

2. Experimental Procedure

2.1. *Test Panels*

The metal couples used in these experiments consisted of a low-carbon steel panel (6x12x0.083 inches) bolted to a copper panel of the same size with Monel metal screws, nuts and washers through three 0.5-inch holes one inch from one of the long edges of each panel, and with three inches between the centers of the holes so that the two panels overlapped. The over-all dimensions of the assembled couples were, therefore, 10x12x0.083 inches. At each of the four corners of the assembly, a ¾-inch hole was drilled on a center one inch from each of the two adjacent sides, to facilitate mounting on racks.

Control panels of the same low-carbon steel and copper, which were not to be coupled, were provided also. These were 6x12x0.083 inches and had a ¾-inch hole one inch from each short end, and midway between the two long sides, for mounting.

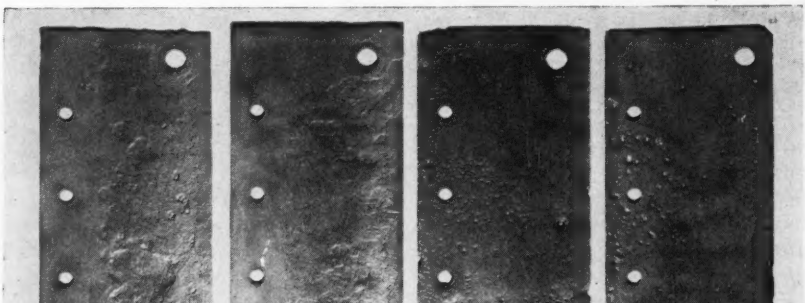

Figure 2—Copper-steel couple test. Six months complete immersion at Kure Beach, N. C. Paint system B, Steel panels after cleaning.

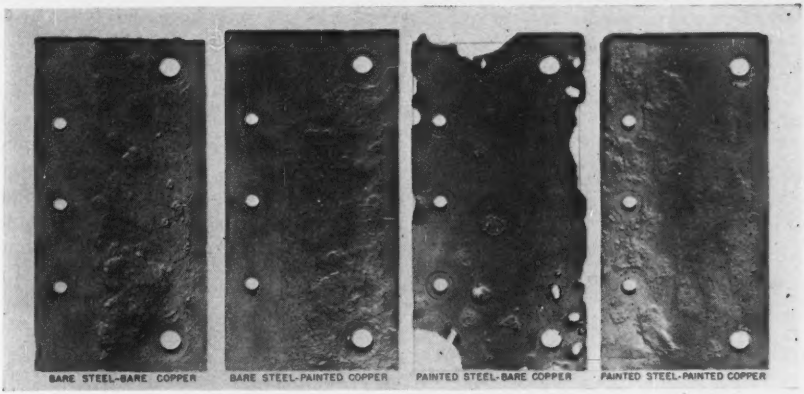

Figure 3—Copper-steel couple test. Twelve months complete immersion at Kure Beach, N. C. Paint System C, Steel panels after cleaning.

2.2. *Paint Systems*

System A. This system was essentially a heat-converting straight phenolic resin which was pigmented with iron oxide. It was spray-applied in three coats. Each coat was baked at 275°F. for 45 minutes before application of the succeeding coat, in the usual manner.

System B. This system consisted of three brush-applied coats of an oil-modified phenolic vehicle pigmented with basic lead sulphate ("blue lead").

System C. This system was made up of two brush-applied coats of an oil-modified phenolic vehicle pigmented with red lead, topped by two brush-applied coats of the same vehicle pigmented with basic carbonate white lead.

System D. This system comprised two brush-applied coats of an oil-modified phenolic-alkyd vehicle pigmented with zinc chromate, followed by two brush-applied coats of an oil-modified phenolic vehicle pigmented with zinc oxide.

System E. This system included two brush-applied coats of an oil-modified phenolic vehicle pigmented with iron oxide, followed by two brush-applied coats of the same vehicle pigmented with zinc oxide.

Paints systems B, C, D and E are typical of the familiar air-drying maintenance or "industrial" paints.

2.3. *Panel Preparation*

The panels described in section 2.1 were first sandblasted to remove scale and other surface contaminants. All the panels were then weighed, to the nearest gram.

The panels which were later to be coupled were divided into two groups, each containing the same number of steel and copper panels. One group was painted on both sides of each panel with the paint systems described in section 2.2. Before painting, circular pieces of masking tape, of the same diameter as the Monel metal washers, were placed over one face of each of the three ½-inch holes along the edge of the panel.

When the paint systems were completed, these discs of masking tape were removed, to expose an area of bare metal around each hole which would subsequently be covered by the Monel metal washers. The purpose of these bare areas was to provide efficient electrical contact, through the Monel metal bolt and nut assembly, between each pair of coupled panels. The second group of panels was left unpainted.

After painting was completed, the panels were assembled into couples, in duplcate, according to the following schedule:

a) bare steel coupled with bare copper;
b) bare steel coupled with painted copper;
c) painted steel coupled with bare copper;
d) painted steel coupled with painted copper.

After the couple systems were assembled, the electrical resistance between each pair of panels was measured. In all cases, this was less than one ohm, indicating good electrical contact. The exposed areas of Monel metal bolts, nuts and washers were covered with the appropriate paint system.

The steel and copper panels which were not to be coupled were then painted with the systems described in section 2.2. Two panels of each metal were prepared with each paint system. Duplicate panels of both steel and copper also were provided as uncoated controls.

2.4. *Test Procedure*

The test panels were mounted on Monel racks and fastened with Monel machine screws. The panels were insulated from the racks by means of Bakelite tubes over the bolt shanks, and by Bakelite washers between the specimens and the racks and between the Monel washers and the bolt heads. Electrical resistance measurements showed immeasurably high resistance between the panels and the racks, indicating that the panels were properly insulated from the racks.

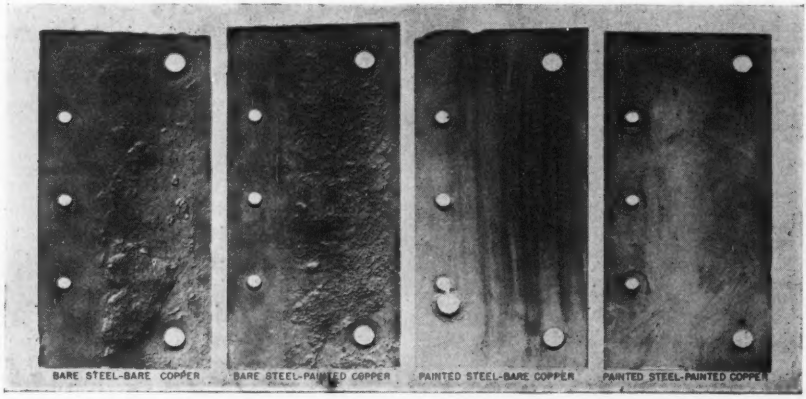

Figure 4—Copper-steel couple test. Six months complete immersion at Kure Beach, N. C. Paint System D, Steel panels after cleaning.

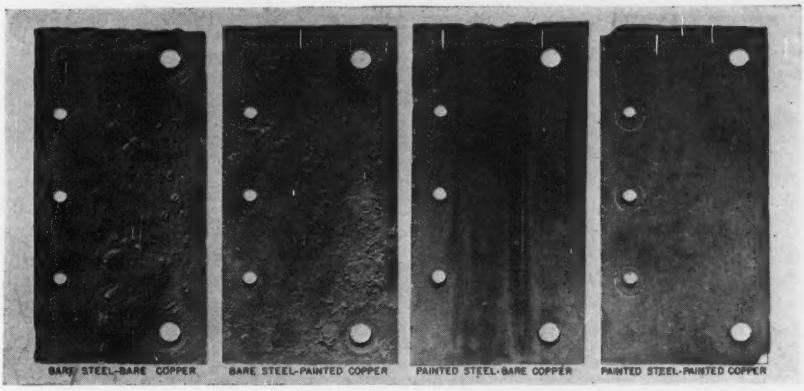

Figure 5—Copper-steel couple test. Six months complete immersion at Kure Beach, N. C. Paint System E, Steel panels after cleaning.

The panels and racks were suspended in flowing sea water (two feet per minute) at Kure Beach, North Carolina, in November. Six months later, in May, the panels were inspected. One set was removed for laboratory evaluation; the duplicate set was returned to the water for an additional six months' exposure period. The panels which were re-immersed were removed in November of the following year.

3. Test Results

At the end of each test period, the panels which were withdrawn from test were disassembled. All corrosion products and remaining paint were removed by careful sandblasting, at 40 pounds gage pressure, for it was previously established that sandblasting at or below this pressure does not cause loss of any substantial amount of metal (less than one gram per square foot). The panels were then weighed, to the nearest gram, and photographed.

Tables I and II record the weight loss of each steel panel at the end of six months' and twelve months' immersion, respectively.

Figures 1-6 are photographs of the steel panels after cleaning by sandblasting.

4. Discussion

Tables I and II show that when bare steel is coupled with an equal

TABLE I

Corrosion of Steel During 176 Days' Immersion in Sea Water at Kure Beach, North Carolina (Milligrams per square decimeter per day)

Paint System	Steel (Not Coupled)	Painted Steel Coupled to Bare Copper	Bare Steel Coupled to Painted Copper	Painted Steel Coupled to Painted Copper
None	22	53, 61	53, 61	53, 61
A	0	25, 29	20	0
B	4.3	16, 27	20, 20	1.2, 3.0
C	2.4, 3.6	4.2	22, 45	4.2, 0.6
D	1.2	6.6, 11	18	0.6
E	0.6	4.2	30	1.2, 1.2

TABLE II

Paint System	Steel (Not Coupled)	Painted Steel Coupled to Bare Copper	Bare Steel Coupled to Painted Copper	Painted Steel Coupled to Painted Copper
None	43	107, 63	107, 63	107, 63
A	0.3	.....	92, 94	0.3
B	5.0	.....	.....	6.8
C	.....	43	.....	24.8
D	0.5	.....	59	2.0
E	2.5	50	33	2.6

area of bare copper the corrosion rate of the steel is increased by a factor of 2-3. If the steel is painted and the copper left bare, the corrosion rate of the steel, as measured by weight loss, is decreased markedly; and the amount of decrease depends upon the individual coating system. If the steel is left bare and the copper is painted, the steel corrodes at its normal, or uncoupled, rate. If both the steel and the copper panel of the couple are painted, corrosion of the steel is essentially prevented.

From the data, based on weight loss, in Tables I and II, it could be concluded that the accelerating effect of coupling with copper may be minimized by painting only the steel member of the couple. However, Figures 1-6 show that such a conclusion is misleading; that, although painting only the steel portion of a steel-copper couple may retard general corrosion, the corrosion which does take place is localized. In every case, perforation and severe edge serration occurred when the steel member was painted and the copper was left bare. When bare steel was coupled to bare copper, uniform attack on the steel occurred but there was no panel perforation or edge serration.

The condition is analogous to that experienced with some anodic inhibitors which may reduce the total corrosion but, if they decrease the anodic area simultaneously, may actually increase the intensity of corrosion. If a coating of paint could blanket an anodic area perfectly, corrosion would indeed be stifled. This, however, is generally not the case. Areas of coating discontinuity either are present initially or develop at some later time. Edges and corners are particularly difficult to coat completely and keep coated. Evidently, painting only the anodic areas may result in considerable reduction of the actively corroding area with marked increase in intensity of attack.

Potential measurements will show that iron is anodic to copper and that the corrosion of iron in sea water is accelerated by contact with copper. However, potential measurements alone will not indicate the corrosion rate, because the rate of corrosion is governed by the polarization of the anode or the cathode or both. It is known that the rate of corrosion of iron coupled with copper in sea water is almost completely controlled by the polarization of the cathode area (copper). Therefore, increasing the copper area will increase the corrosion of the iron. If, however, the copper area is held constant and the anode area (iron) is decreased, the total amount of

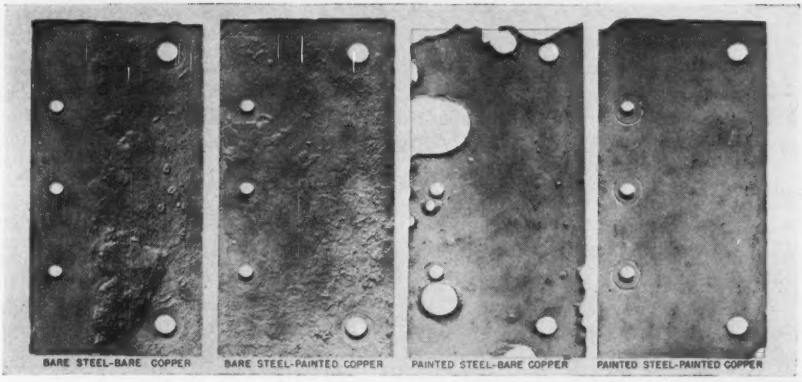

Figure 6—Copper-steel couple test. Twelve months complete immersion at Kure Beach, N. C. Paint System E, Steel panel after cleaning.

corrosion of the iron area still will be constant, always providing the accumulation of corrosion products on the corroding surface does not materially stifle the reaction. In our experiments, the anode area was reduced very markedly but, because the corrosion reaction was largely under cathodic control, the total amount was not materially reduced. The intensity of attack at small areas of paint discontinuity was actually much greater than it was when corrosion spread over the entire steel areas on the uncoated couples.

It is noteworthy that paint system A (the iron oxide-pigmented baked phenolic), which effectively prevented corrosion of the steel when

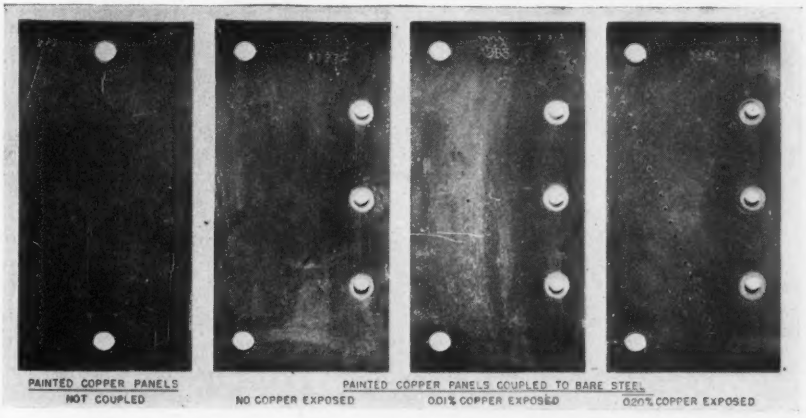

Figure 7—Effect of painting cathodic areas. Painted copper-bare steel couples immersed in sea water at Kure Beach, N. C. for six months. Paint system: Four coats iron oxide pigmented heat-reactive phenolic enamel.

it was not coupled to copper and when both the copper and steel were coated, provided the poorest protection when applied to steel coupled with bare copper. Paint system A would undoubtedly have been superior to the other systems if applied at equivalent thicknesses. However, its total coating thickness was not equal to that of the orthodox paints, and there were many small discontinuities which were not evident at the beginning of the test, which resulted in local attack at many more spots than occurred on panels coated with the other paint systems. Although paint system A was not a continuous barrier initially, it protected uncoupled steel better than the other paint systems, probably because the tiny discontinuities soon clogged with corrosion products and stifled further corrosion.

It might be pointed out that, if heavier-gauge panels had been used, the tendency toward perforation would have been lessened, not only because insoluble corrosion products could accumulate in the pits and thus retard corrosion, but also because, in corroding, the anodic areas would have increased and the intensity of attack would have decreased.

In any case, accelerated localized corrosion must occur at paint discontinuities and must result in deep pitting and sometimes in perforation. Painting only the anodic area of a strong couple should be regarded as unsafe practice.

SECTION II. THE EFFECT OF PAINTING CATHODE AREAS

In another series of experiments, we attempted to determine the corrosion rate of bare steel panels coupled to imperfectly coated copper cathodes.

5. Experimental Procedure

5.1 *Test Panels*

The test panels were of the same type and size as those described in section 2.1.

Figure 8—Effect of painting cathodic areas. Painted copper-bare steel couples immersed in sea water at Kure Beach, N. C., for six months. Paint system: Two coats Navy Chromate Primer 52(P)18; two coats zinc oxide pigmented phenolic paint.

5.2 *Paint Systems*

System F was an iron oxide-pigmented, heat-reactive phenolic vehicle spray-applied in four coats. Three of the coats were each baked at 360° F. for 10 minutes; the final coat was baked at 360° F. for 20 minutes.

System G consisted of two brush-applied coats of Navy Specification 52(P)18 chromate primer, followed by two brush-applied coats of an oil-modified phenolic vehicle pigmented with zinc oxide.

System H comprised four brush-applied coats of an alkyd-chlorinated rubber paint pigmented with titanium dioxide.

5.3 *Panel Preparation*

As described in section 2.3, the areas around the three ½-inch holes on all panels to be painted were covered with masking tape. Each of the three paint systems outlined in section 5.2 was applied to six copper panels. When the paints were thoroughly dry, the masking tape was removed. The panels were then divided into three sets each containing two panels coated with each paint system. One set received no further treatment. A ⅛-inch hole was drilled through the center of the second set, thereby exposing 0.033 square inches of bare copper. Twenty ⅛-inch holes, ½-inch apart, were drilled along one diagonal of each panel in the third set, thereby exposing about 0.7 square inch of bare copper. The three sets of coated copper panels were then coupled, as described in section 2.3, with previously weighed bare steel panels. Couples of bare steel-bare copper and painted single specimens of copper (not coupled) were included as controls.

These panels were immersed in flowing sea water at Kure Beach in the same manner as the previous series, described in section 2.4.

6. Test Results

After total immersion for six

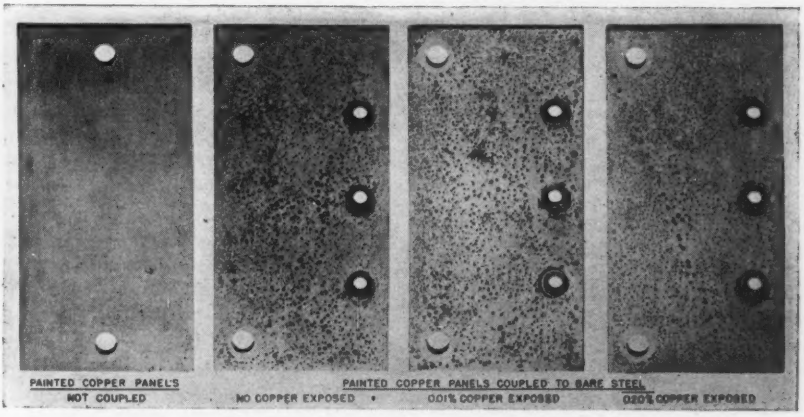

Figure 9—Effect of painting cathodic areas. Painted copper-bare steel couples immersed in sea water at Kure Beach, N. C., for six months. Paint system: Four coats pigmented chlorinated rubber.

months, the panels were removed. The steel panels were sandblasted to remove corrosion products and were weighed. The coated copper panels were carefully cleaned of fouling organisms without removing the paint, and were photographed.

Table III records the weight loss of each of the steel panels. Figures 7, 8 and 9 are photographs of the coupled painted copper panels after immersion for six months in sea water.

7. Discussion

The data in Table III show that painting only the copper portion of steel-copper couples reduced the corrosion rate of bare steel to that of uncoupled bare steel, when the coating coverage was essentially complete. However, when small areas of copper were intentionally left bare, the corrosion rate of the coupled bare steel member was, in the majority of cases, significantly greater than the rate when bare copper was coupled to bare steel. This finding was unexpected, and the experiment should be repeated. If, as is commonly believed, the corrosion of steel coupled with copper is under cathodic control, the corrosion rate of steel would decrease as the cathode area is decreased. In our tests, however, the corrosion rate of steel for a number of cases was substantially higher than the control when only 0.01 or 0.2 percent of the total area of copper was exposed. The data cannot be ignored, but at present we have no explanation for the phenomenon.

TABLE III
Corrosion Rate (in Mdd.) of Bare Steel Coupled with Painted Copper

Copper Area Exposed, Percent	Paint System		
	F	G	H
0	38, 45	26, 47	34, 86
0.01	103, 108	47, 83	29, 250
0.20	178, 70	91, 66	115, 158

Bare steel, not coupled: 32 mdd.
Bare steel coupled with bare copper: 67 and 64 mdd.

What is more significant, perhaps, is the condition of the paint systems on the copper panels. Figure 7 shows paint system F (the baked phenolic coating) in perfect condition. Figure 8 shows that the pigmented oil-modified phenolic paint remained in excellent condition when the copper was not coupled to bare steel. When coupled, the coating peeled from the edges and around the bare areas. Figure 9 shows that the pigmented alkyd-chlorinated rubber system remained intact on the uncoupled copper panel, but produced many holes when on copper panels which were coupled to bare steel. These "holes" were probably blisters which were broken when the fouling organisms were scraped off. They have no relationship to the original bare areas or to the panel edges.

The three paint conditions can be explained readily on the following basis: When copper is coupled to steel, the copper is the cathodic member, and hydrogen is evolved at the cathode as a result of the corrosion reaction. The evolvement of hydrogen leaves an excess of hydroxyl ions which renders alkaline the area immediately around the cathode. Consequently, the oil-base phenolic paint (Figure 8), which is not alkali-resistant, is extensively deteriorated near the bare areas, where alkali was produced as a result of hydrogen gas evolvement. The alkyd-chlorinated rubber system (Figure 9) is quite alkali-resistant

but rather permeable. It was not affected by the formation of alkali at the exposed cathode areas, but the production of hydrogen beneath the coating caused pin-point blistering. The baked phenolic coating (Figure 7) is much more alkali-resistant and less permeable than the oil-modified phenolic paint, and it has better adhesion than the alkyd-chlorinated rubber paint. It was not damaged by either the formation of alkali or the evolvement of hydrogen.

8. Summary

These experiments show that the selection of a satisfactory protective coating should not be made solely on the basis of the paint system, and that the stucture which is to be coated should also be considered. If galvanic or even stray electrical currents from external sources are present, painting only the surfaces to be protected may be dangerous. If the surfaces are not perfectly coated, accelerated corrosion will occur at the areas of paint discontinuity, which localizes the corrosion caused by galvanic or stray currents, and may eventually perforate the metal at these areas of localization. If the effects of corrosion are not localized by imperfect coating, the structure may have a longer useful life if left unpainted.

All the probable corrosion reactions which can occur should be taken into account, when paint is to be applied to metal surfaces which are to be immersed in aqueous environments. If galvanic corrosion can occur, painting only the anodic areas may cause intensified local attack at the points of paint discontinuity. For areas which may become strongly cathodic, a paint vehicle should be selected which has at least reasonably good resistance to alkali.

It is the safest practice to paint both anodic and cathodic areas with the best alkali-resistant paints or coatings available. Care should be exercised to avoid pinholes, uncoated edges, faying surfaces and similar foci for localized galvanic attack.

Permeability and Corrosion in Protective Coatings

By Dr. D. F. Siddall
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THEORETICAL considerations on permeability have attracted the attention of many able and distinguished physicists and chemists during the last decade. More particularly has this been so with the advent of increased activity in the field of high polymer chemistry. Typical examples of such work can be found in the extensive survey of membranes and permeability problems in a series of papers by Manegold, Adam, Langmuir, Kline, Hober, Brabender, Browne and others. Such research has involved highly theoretical thought and complicated methods of study, involving innumerable assumptions that required advanced technique and equipment to establish their validity. Today, a large portion of this work remains still to be correlated. But the picture as a whole has been slowly and steadily clarified by means of a more fundamental study of the nature of polymeric films.

The term permeability must not be confused with porosity; inasmuch as a micro-porosity, while it could in some instances be classified as permeability, does not embrace all factors which cause permeability. Macro-porosity usually may be attributed to aggregates which, because of their size or mode of formation, produce a large pore or point of entry. Permeability, diffusion, and osmosis must all be considered in the study of foils and membranes; but for practical use in protective coatings, permeability and diffusion only need be discussed. Permeability coefficients and diffusion constants are interrelated by the partition or absorption coefficient.

The methods of evaluating the permeability of a film are rather simple, and as a rule follow the general pattern of determing the weight loss of the permeant through a definite thickness and area of film, under constant or controlled pressure differentials, per unit of time. Such tests, of course, are conducted within specified and closely controlled temperature limits. The diffusion constant thus indicates the number of grams of water per hour which will pass through one cubic centimeter of the sample under a vapor pressure difference of one millimeter of mercury. This may be calculated from Ficks Diffusion Law, as described by Taylor, Hermann and Kemp (1) the constant being multiplied by 10^8. In the case of gases, permeability is defined as the number of cubic centimeters per minute passing through a membrane one centimeter thick, and one square centimeter in cross-sectional area, when it separates air at atmospheric pressure from the gas at a pressure of 30 millimeters of water above atmospheric.

The physical aspects of permeability and their theoretical derivation are quite involved and are beyond the scope of this paper. However, in connection with protective

coatings, attention must be directed to the differences in diffusion through supported and unsupported films. In unsupported films, Ficks diffusion law can easily be verified within the limit of experimental error. Supported films, such as usually are encountered in paints, lacquers, enamels, and the usual protective coatings, present an entirely different set of conditions, most important of which are: the physico-chemical make-up of the film, and its relation to the surface being protected. It can be seen that in the case of such supported films, having intimate and molecular contact with the substrata, the pressure differential is reduced to zero, provided that the support for the film in itself is impermeable. Such is not the case when the support is porous or permits passage of the permeant. An example is untreated paper or cloth.

Permeable supports alter the diffusion coefficient, largely due to a decrease in the area on the contact surface of the film, or because they impede the passage of the permeant. Films attached to an impermeable support permit such passage through the film only under conditions where the support itself has been altered by chemical or physical breakdown, dependent upon its absolute permeability when unsupported. Protective coatings or films applied to metals, in conditions where a corrosive substance may permeate the film, may cause an increase in the pressure differential, and in extreme cases may reverse the pressure by means of the generation of gases or vapors due to the interaction of the corrosive agent and the impermeable support or backing.

Low permeabilities of the film eventually reach an equilibrium under such conditions. It is towards this goal that new methods and materials for protective coatings are continually being improved and formulated. High permeabilities of the film permit further chemical reaction with increased pressure, followed by lifting of the film, destroying the adhesion and eventually leading to a complete breakdown of its protective ability.

Permeability and Polymer Films

Proceeding to the relationship of permeability and polymers, it is found that the chemical composition, physical size of the film-forming polymer, and the method by which the coherent film is formed, have the most important bearing on its diffusion constant, and on its final protectability.

Extensive tests have been conducted on practically all materials having some physical cohesion or ability to form a continuous, homogenous layer. Classifying such polymers for purposes of simplicity in discussing its relationship to protective coatings, it is convenient to use two basic types: the converting, chemically reactive or curing type; and the non-converting, non-curing type. The former will be recognized as a thermosetting polymer and the latter as a thermoplastic. The curing, or thermosetting, type polymer in general exhibits a lower initial permeability, because of the lower average molecular weight, the presence of both small and large polymers, the establishment of cross-linkages during a cure, and the absence of materials which tend to absorb the permeant. In contrast to this, the

non-curing or thermoplastic polymer, when properly processed and compounded, although giving slightly higher permeabilities, will not show a tendency to increase in its permeability; in fact, may improve with age. This is not generally true with a curing film, which, by virtue of a chemical reaction which forms the film, ultimately breaks down, either internally or externally with age, or in contact with highly oxidizing substances.

It is rather difficult to draw any definite conclusions as to the effect of high and low molecular weight polymers on permeability. Such relationships depend solely upon the manner in which the film is formed and upon the presence of additives which assist or modify the resultant film. It has been shown by Kittelberger (2) and Dantuma (3) that there exists little correlation between the original permeability and durability of the curing type films. But this must be predicated upon the effect of age on the physical structure of the film. It is shown, however, that permeability decreases slightly with age because of the densification of the film, but eventually this will cause failure and high diffusion rates because of continued oxidation or polymerization. Plastic films illustrate the point in question. Phenol-formaldehyde films have a D value of 0.1×10^8, whereas polyvinyl chloride gives 0.5×10^8. As the molecular weight of the polymer decreases, a decrease in the diffusion constant may be expected. In the case of the polyvinyl chloride-acetate copolymers, an increase in the acetate content shows a corresponding increase in the permeability. In varnishes, enamels, synthetic and drying oils, it is found that permeability increases with an increase in the ratio of oil to resin; or short oil varnishes have less permeability than long oil varnishes. In such films formed by oleo-resinous materials, water is imbibed by the oily film and forced through the interfibrillar spaces under the influence of capillary forces.

Protective Coatings and Polymers

The next consideration must be given to the mechanics and chemistry of film formation from polymers. In the thermoplastic type of resins in which no chemical reaction takes place, the film is formed solely by the evaporation of the solvent. As the film is applied by conventional methods, the solvent immediately starts to volatilize. During this process, the long fibular polymers orientate themselves according to their polar characteristics and interlace themselves into a continuous matlike film. As more solvent leaves, this structure approaches a gel-point, under which conditions orientation or neutralizing movements of the polymers are decreasing. At the gel-point, the structure is fixed and no further flow will take place without the addition of heat. The solvent then continues to evaporate, and the film becomes harder and thinner; but the rate at which the solvent leaves the film is steadily decreasing.

In the thermosetting, curing or oxidizing type polymers, the method of film formation is considerably varied. Initially, solvent or thinner starts to volatilize. Almost immediately, especially in fast drying, air-curing varnishes or enamels, the

molecular aggregates which are formed in the early stages of drying or formed during storage, arrange themselves into long fibre-like chains and gradually orientate themselves into slightly immobile bundles. The drying process then proceeds in two steps which may vary considerably in their extent and generally overlap each other. The first stage consists of oxidation which is the primary cause of the initial film formation after the release of the solvent, followed by an absorption of oxygen, converting the unsaturates and creating an acid-ester interchange. The next stage involves polymerization in which the aggregates, both small and large, knit together by the usual processes of the polymerization reaction. This latter stage is more predominant in certain types of oils, such as wood oil, is the prevailing reaction that takes place and forms the hard film when subjected to elevated temperatures, and results in films of greatest resistance and durability.

The effect of polymer size is of most importance in the formation of the film. Large polymers require stronger solvents, and these are generally slow evaporating. Large polymers tend to hold back, or retard, because of their solvent retention. Lower total solids are accounted for in the use of large polymers because of their viscosity characteristics. Small polymers dissolve readily in fast-evaporating, cheaper solvents, release the solvent, and provide a more adaptable solution because of their range of viscosities and higher solids content. Large polymers in general show greater resistance, stronger and more flexible films, having more cohesion than adhesion; while the smaller polymers exhibit decreased resistance and tend to promote greater adhesion than film cohesion. In either case, solvent balance (with respect to viscosity, solids, drying rate, cooling or blushing effect) must be such that, at no time, should a surface skin form which retards the release of the solvent entrapped below the surface. The solvent should dry at such a rate as to allow the film to flow out thoroughly and form a bubble-free, continuous film. A slow-evaporating solvent increases the permeability if it is a poor solvent; but on long drying, and especially when subjected to heat, a decrease will be noted. Conversely, with a good solvent, the permeability decreases. This is pronounced in films drying by evaporation only. The effect of other additives (such as fortifying resins, driers, plasticizers, pigments and fillers) produces a variety of combinations which will classify and establish the type of films formed.

Protective Coatings and Permeability

The physical aspects of permeability and films formed from polymers, protective coatings, and their methods of forming films have been compared. It remains now to consider a more vital relationship—that of the usual protective coating or paint film and its diffusion characteristics. In addition to the molecular size and composition of the basic film forming polymer, it is quite necessary that modifying or compounding additives be blended to impart the necessary properties in the final coating. These ingredients, of which there are many, have an important bearing on permeability.

Pigments and fillers are added for both protective and decorative effects. As a rule, the addition of pigments and fillers decreases the permeability, largely due to their blocking effect. There is, however, an optimum ratio that varies with the particular pigment, or filler size and composition, to produce a film of minimum permeability. Pigment requirements for low permeabilities are: concentration, dispersion flocculation, size, shape, and wetting characteristics. These, however, assume that there is no chemical reaction between the resin and the pigment, in which case metallic soaps are formed, and the water resistance is improved. However, when acidic products result from such a chemical reaction between resin and pigment, water soluble products may form, which naturally increase the permeability.

Some pigments or fillers increase the permeability because they retard the drying of the film, although the permeability decreases in this case with age, due to the progressive reaction of oxidation and polymerization. Absorbent pigments or fillers increase permeability by transfer or capillary action. In this connection, aluminum flake or mica reduce permeability, because of their layer formation and tendency to overlap, thus impeding any passage through the film.

The effect of plasticizers or softeners vary in their ability to raise or lower the diffusion constant. Plasticizers having high solvency powers to promote a more complete fusion and flow out of the resin are generally used to improve the permeability. Slightly incompatible materials, such as waxes, and certain types of resins and oils, tend to reduce the permeability. Incompatible hydrophobic materials lower the diffusion, due to a slight sweating out, blooming or bleeding to the surface of the film, forming or improving the continuity of the surface.

The physical treatment given a coating, either during its formation or drying or in actual service, will regulate its permeability. If a coating is baked, lower permeabilities are expected because of the more complete release of the volatiles, and the establishment of continuous pinhole free layers. Aging decreases permeability in air drying films; but this varies widely with the type of materials, and reaches a point, in the case of the curing or oxidizing type of coating, where permeabilities may show a large increase due to cracking or weathering. Mechanical abuse, inasmuch as it will abrade, tear, puncture or compress a film, destroys the best of paints. Freezing or crystallization within any minute pore will rupture the film, enlarge the pore, and increase the permeability. Permeability will govern the adhesion of a coating to its base surface by regulating the interchange of moisture or corrosives and the support. This is predominant on wood or like surfaces having a slight porosity. In these cases, the film must breathe; otherwise adhesion is lost and the film will lift or detach itself, due to vapors evolved or entrapped at the boundary surface. A careful regulation of this passage must take place, otherwise its protective value is lost. On metals in particular, rust formation loosens the adhesive bond and the film will

fail physically. Iron salts may form, diffuse into the film, precipitate iron hydroxide and weaken the resistance.

Up to this point, the water permeability has been referred to. Summarizing the conditions affecting water resistance and permeability, we find that these conditions are:

1. Absorption of water vapor by the film.

2. Condensation of liquid on the surface of the film, influencing the absorption.

3. Imbitition pressures developed in the film as determined by the relative polarity and structure of the film.

4. Swelling of the film because of a distention of its structure by imbibition forces.

5. Flow of water through spaces of the distended film.

6. Diffusion of water due to solvation of the film polymer or materials contained in the film.

7. Temperature and pressure conditions.

Chemical Attack and Permeability

These conditions, as well as considerations given other factors relating to permeability and water transmission, apply equally to other liquids. In the case of corrosive liquids or atmospheres in contact with a protective coating, accelerated aging and chemical breakdown add to and complicate the question of permeability. It is under these severe conditions that the ordinary protective coating cannot stand the test and maintain its low diffusion values. A more comprehensive situation exists when chemical attack and permeability are evaluated. Applied to protective coatings, five types of attack may be listed:

1. Penetration of the permeant in the same manner as in the case of water; but in this case, the permeant is an electrolyte.

2. Accelerated oxidation of the film by hastening the cure of the film to the point where it physically fails.

3. Retarding the oxidation of the film when in contact with reducing atmospheres, resulting in a slower drying time, thus an increased diffusion rate.

4. Contact with corrosive substances containing solvents or compounds having solvent action on the film.

5. Chemical disintegration or reaction, either of the polymer itself or contained additives and modifiers.

Comparing these conditions to those stipulated for low permeabilities to water, it can be understood readily that, because of these conditions and the endless variations possible, an impermeable coating, resistant to physical abuse, chemical disintegration, and age requires a radically different approach in its formulation and application. A film may be composed of a network of neutral, acid, basic or amphoteric substances. Its composition determines the electrical charge on the membrane. Permeability, then, will depend upon the pH of the electrolyte in contact with the membrane and the charge on the membrane. With a high polymeric acidic film, permeability to cations will be high, and conversely, a basic film, permeable to anions. This condition dictates that the film, in the average case, should be judged in its permeability in relation to the acidity or basicity of the corrosive permeant.

Permeability and Chemical Industries

Permeability should be given prime consideration by every engineer whose problems involve corrosion and materials to prevent corrosion. While it is true that practically every severe case of corrosion must be singly and individually dealt with, there exists a large portion of corrosion which by its very extent, and not necessarily its severity, can be satisfactorily solved by the proper choice of protective coatings. It is, by and large, a question of permeability coupled with chemical attack that should segregate the good and eliminate the poor. Constant research and comprehensive development in protective coatings strive to obtain a universal barrier of protection; but realization of this object follows in a parallel manner our knowledge of the large, fibre-like molecular aggregate, the polymer.

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Officers of N.A.C.E. for the year 1946-47. At the left O. C. Mudd, re-elected Treasurer; in the center President Francis J. McElhatton; at the right, Vice President G. R. Olson.

Prevention of Condensate Well Corrosion by Chemical Treatment in the Erath Field

By W. D. Yale
Chief Engineer, Gas & Gasoline Cycling Plant, The Texas Company, Houston, Texas

THE Erath Field is located in Vermillion Parish, in the coastal area of Southern Louisiana. It is approximately 10 miles southeast of Abbeville and four miles south of the town of Erath. The field is on a domal uplift, roughly five miles in diameter. It was discovered in April, 1940. There are 19 gas condensate sands in the unitized portion of the field, ranging from 8,100 to 11,970 feet in depth.

The Erath Field was unitized in order to realize maximum recovery of petroleum hydrocarbons with a minimum of waste. A 220 million cubic foot per day cycling plant was installed by the unit and put into operation on April 11, 1944. Production is being obtained at present from eight of the producing sands,

TABLE I
Erath Cycling Plant
Summary of Data from Caliper Survey on Top 1000 Feet for April, 1945

UNIT	Depth	Tubing Size API OD	Wall Thickness	Tubing Type	No. Pits with Depth in Excess of 30 Percent Wall Thickness	No. Pits with Depth in Excess of 39.4 Percent Wall Thickness	Depth of Deepest Pit. Inch	REMARKS
33-2.....	10,400	3½	0.254	N-80	19	6	0.11	Tubing Pulled
33-1.....	10,400	3½	0.254	N-80	20	4	0.11	Generally corroded
32-4.....	10,400	3½	0.254	N-80	11	3	0.125	Rest joints in fair shape
3-3.....	10,400	3½	0.254	N-80	13	3	0.105	*Generally corroded
38-1.....	10,400	3½	0.254	N-80	15	1	0.11	Generally corroded
3-5.....	10,400	3½	0.254	N-80	10	2	0.10	Rest joints in fair shape
3-6.....	10,400	3½	0.254	N-80	16	0	0.095	Generally corroded
3-1.....	10,100	2⅞	0.217	N-80	1	0	0.07	Very little corrosion
32-6.....	10,100	2⅞	0.217	N-80	7	5	0.17	Rest of joints in fair shape
41-1.....	10,100	2⅞	0.217	N-80	8	2	0.11	Rest of joints good shape
47-2.....	10,100	2⅞	0.217	26 N-80	0	0		No appreciable corrosion
				7 J-55	0	0		
32-1.....	10,800	3½	0.254	N-80	2	0	0.09	Rest joints slightly corroded
4-1.....	10,800	3½	0.254	N-80	1	0	0.08	Very little Corrosion
32-5.....	10,800	3½	0.254	N-80	0	0	0.06	Practically no corrosion
3-4.....	11,300	2⅞	0.217	N-80	6	5	0.2	Rest joints no corrosion
3-2.....	11,300	2⅞	0.217	N-80	1	1	0.11	Rest joints no corrosion
35-1.....	11,600	3½	0.254	N-80	0	0	0.00	Retubed April 27, 1945
32-2.....	8,700	2⅞	0.217	32 N-80	9	7	0.2	Rest joints no appreciable
				5 J-55	0	0	0.00	corrosion

In the wells where there is very little corrosion other than the few deep pits recorded, it is believed that the pits may be due to something inherent in the tubing or caliper and are not due to corrosion. However, they show up as pits on the Caliper survey.

* Generally corroded—Nearly all joints corroded 0-1′ from the ends but to less depth than recorded pit.

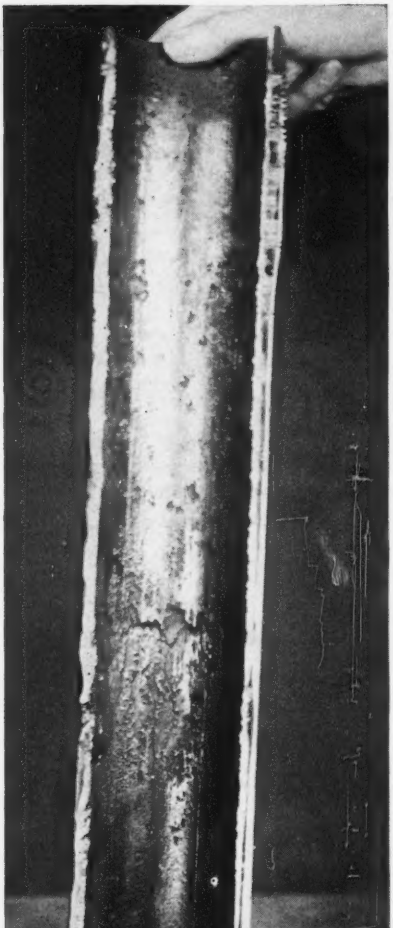


Figure 1. A section of 3″ tubing from Well 35-1, in 11,600 feet sand, removed from the producing string after seven months' service. This is the pin end of joint No. 399 (numbered from bottom), from a depth of approximately 1200 feet. The direction of flow, as the picture is taken, would be downward. The deepest pit in this section is approximately 0.1 inch.

with all residue gas, after shrinkage and fuel, being returned to the producing formations to insure pressure maintenance, maximum recovery, and to prevent waste.

Corrosion first became apparent in the Erath Field when it was necessary to replace certain wing valves and choke tips after only five months of operation. At that time, it was hoped that corrosion was of a minor nature. However, in March, 1945, it was necessary to work over one of the wells producing from the 11,600-foot sand. It was then discovered that corrosion was extensive in this well and that replacement of the entire tubing string was required. There were 142 joints in this string in which corrosion had reduced the wall thickness by 15 to 30 percent. Figure 1 is a photograph of the pin end of one of the joints of N-80 tubing removed from this well. This joint is typical of the corrosion observed throughout the string, showing all of the corrosion to be concentrated above and below the collars. The maximum distance to which the corrosion extended was 18 inches above and below the collars. The severe corrosion area appeared to be three to three and one-half inches wide, and a distance nine to 11 inches from the end of the joint. When results of corrosion in this well were reviewed, after only seven months' production, caliper surveys were run on all wells producing through the tubing. A summary of the data obtained by this survey is given in Table I. These data indi-

cated that the 10,400-foot and 11,600-foot zones were the most corrosive. The other producing zones were indicated to have a lesser corrosive condition, with the shallowest zones being at a minimum.

It was apparent from these data that the most corrosive wells would have to be retubed immediately, and thereafter at periods of less than 18 months, if something could not be found to reduce or eliminate corrosion. Consequently, considerable thought was devoted to this problem; and a study of all possible means of eliminating this corrosion was started.

The corrosion is of the acid attack type and is believed to be caused by dissolved carbon dioxide or organic acids, or by a combination of both.

Method of Test

In order to evaluate fully the extent of corrosion and the benefits of remedies employed, three methods of test and control are used. These are internal tubing caliper surveys, water analysis, and coupon exposure tests.

Original work in the field with caliper surveys was experimental, but as data were obtained a procedure was developed whereby reliable interpretations were possible. Table II shows a comparison of caliper survey data with those obtained, after the tubing had been pulled, by an internal tubular inspection firm utilizing a pit gauge, and by visual inspection of pipe sections by the unit engineers. Reasonable agreement was found between the three methods but the caliper survey did not indicate the full depth of all pits. In a few cases where ring corrosion occurs, the caliper indicates a greater depth than actually exists. This is caused by the fact that the caliper measures total increase in diameter, which must be assumed to occur all on one side. Due to anomalies existing in the tubing which might be considered corrosion, a caliper survey is made on each new string of tubing installed as a basis of comparison for later checks.

Caliper surveys at Erath are being made at approximately three months' intervals on key wells, in order to keep a close check on corrosion conditions in the field.

TABLE II

Comparison of Caliper Survey, Internal Tubular Inspection, and Visual Inspection Data Made on Top 114 Joints of Tubing From Well 33-2.

I. Caliper Survey vs. Internal Tubular Inspection:
   1. Caliper checks 35 percent of pit gauge values.
   2. Caliper shows 6 percent of joints to be in worse condition than pit gauge survey.
   3. Caliper shows 59 percent of joints to be in better condition than survey.

II. Caliper Survey vs. Visual Inspection:
   1. Caliper checks 16 percent of visual values.
   2. Caliper shows 20 percent of joints to be in worse condition than the visual survey.
   3. Caliper shows 58 percent of the joints to be in better condition than the visual inspection.

Notes:
1. Caliper Surveys were run with the tubing in the well.
2. Internal Tubular Inspection was made with a pit gauge after the tubing was removed from the well.
3. Visual Inspection was made after splitting the pit but without a pit gauge.

Water Analysis

Water samples are obtained both from the Erath unit portable separator and from sample bombs located

at the orifice fittings on the gathering lines.

The water samples have been analyzed for iron, organic acids, chloride, calcium, magnesium, and alkalinity. The pH of the water is determined immediately upon sampling with a laboratory model pH meter.

The analysis for iron was made by the dichromate method as outlined by Scott (1). In waters colored with the dichromate, a gravimetric analysis was made including the modification as set out in Treadway and Hall (2).

The determinations for calcium, magnesium, and alkalinity were made following the methods of the American Public Health Association (3).

The determination of chromate was made from an acid solution with potassium iodide and titrated with standard sodium thiosulfate.

The organic acids present were determined by the Humble method as outlined in the NGAA proceedings. Concentrations of organic acids were found ranging from 80 to 400 ppm.

A water control outline has been adopted at Erath for the testing of iron bicarbonate, chromate, and chloride in well-head waters. This outline is considered as being sufficient for practical applications in the field. Table III is a typical report.

Coupon Tests

Coupons, 1 x 9 x 1/16-inches, made of SAE 1020 steel are used in the well heads to establish corrosion rates on wells before and after chemical injection. The coupons are suspended in the well head by means of a ½-inch hydraulic pipe screwed in the cap at the top of the Christmas tree. The pipe is of such length that the top of the coupon is one inch below the flow line outlet of the tee, or cross. There are two ¼-inch holes ⅜ and ⅝-inch from one end of the coupon by which it is attached to the hydraulic pipe with quarter-inch bolts and nuts.

Before the coupon is placed in the well head, it is cleaned and polished with 00 steel wool, then degreased with carbon tetrachloride, dried and weighed. Upon removal from the well, the coupon is cleaned with a powdered cleanser and steel wool to remove the corrosion products. From the loss in weight and period of exposure the corrosion penetra-

TABLE III

Water Analyses for Field Well Corrosion Control

Well No.	Iron FE	Chromate CrO_4	pH	Chloride Cl	Bicarbonate HCO_3	Calcium Ca	Magnesium Mg	Sulfate SO_4	Sodium Na	Total Solids	Remarks	
3-3	No Sample Taken—Caliper Survey											
3-5	111	0	6.63	0	268						No Pump	Lbs.
3-6	5—	510	6.21	....	....	Pump	Discharg	e Line Br	oken		5 Gals.	5
32-1	5—	691	6.02	....	....						10 Gals.	4
32-4	5—	407	6.11	....	....						10 Gals.	4
32-5	196	0	6.70	0	439						No pump	
33-1	5—	657	6.06	....	....						10 Gals	4
33-2	5—	637	5.78	....	....						10 Gals.	4
33-5	31	2008	5.93	....	....						10 Gals.	5
35-1	242	0	6.57	0	488						No pump	
38-1	59	0	6.84	40	1342	Shut-in	bottom h	ole press	ure surve	y	6 Gals.	20

Note: All treated wells using dichromate.

tion in inches per year is calculated. Figure 4 shows the comparison of corrosion rates both before and after chemical injection. Several coupon tests have been run on each well, but only average values are given in the figure.

A general correlation appears to exist between the amount of iron present in the produced water, the corrosion rate from coupons, and the caliper surveys.

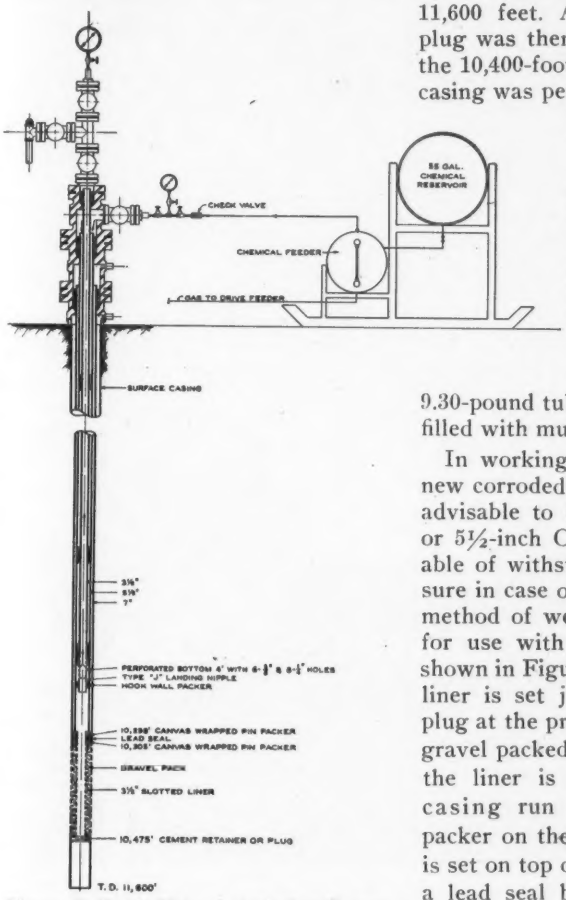


Figure 2. Erath Unit. A typical well completion and chemical injection set-up.

Description of Well Completion and Chemical Injection Equipment

When the wells were originally drilled for completion in the 10,400-foot zone, 10¾ inches O.D. casing was set to approximately 2,300 feet and seven inches O.D. casing was set to a total depth of approximately 11,600 feet. A cement retainer or plug was then set at the bottom of the 10,400-foot sand section, and the casing was perforated above and below the producing zone for cement squeeze jobs to shut off water. The producing section was then perforated at the producing zone. Production was obtained through 3½-inch O.D. J-55 and N-80 eight-round form external upset EUE T & C 9.30-pound tubing, the annular space filled with mud.

In working over the wells to renew corroded tubing, it was deemed advisable to install an additional 5 or 5½-inch O.D. casing string capable of withstanding full well pressure in case of a tubing failure. The method of well completion adopted for use with chemical injection is shown in Figure 2. A 3½-inch slotted liner is set just above the cement plug at the producing formation and gravel packed. The packer on top of the liner is set and the 5½-inch casing run in the hole. A pin packer on the bottom of this casing is set on top of the first packer, with a lead seal between. The 3½-inch O.D. Hydril external upset EUE in-

ternal flush J-55 fully normalized 10.20-pound tubing, with the bottom four feet of the first joint perforated with 14 small holes, is then run in the well and set with a hookwall packer approximately 20 feet above the gravel packed section.

Injection of chemical is made into the annulus between the 3½-inch O.D. tubing and 5 or 5½-inch O.D. casing. The chemical trickles down the casing through the tubing perforations and is carried up the tubing by the velocity of the gas stream.

This method of chemical injection is felt to have contributed a great deal to the encouraging results experienced in the Erath Field to date.

The chemical injection equipment is shown in Figure 3 and consists of a diaphragm-operated type chemical injection pump set on movable skids, with a 50-gallon reservoir for chemical solution storage. The pump is operated by 50 psi gas pressure on the diaphragm. The unit is quite compact and easily handled. The usual volume pumped is 10 gallons of solution per day, but the feeder has a capacity of 15 gallons per day.

The connections from the pump discharge to the well fiittings are of copper tubing, with a check valve placed as close to the wing valve as practical to insure a positive shut-off in the event of a line break.

Chemical Injection

Corrosion control at Erath was undertaken on a practical basis as a protective measure only, and was not considered in the light of a special research problem. It was felt that fundamental data could be obtained best through close cooperation with the NGAA, NACE and API committees in establishing and carrying out a research program. Exhaustive studies were not made in the unit laboratory or field to determine the causes or type of corrosion,

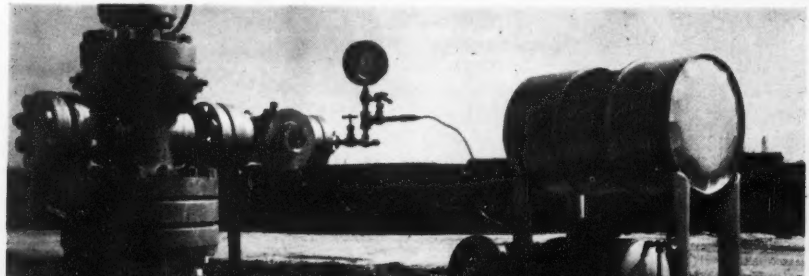


Figure 3. A close-up view of a typical chemical treating unit of a well producing from the 10,400 foot zone. Note chemical pump arrangement and chemical lines to wing valve connections and compactness of setting.

but only sufficient analyses of well head water samples and coupon test data were taken for a quick determination of results from a few well known chemicals for corrosion control.

The two main chemicals used in the Erath Field were sodium dichromate and sodium hydroxide. Sodium dichromate was first used because of its known corrosion inhibiting qualities in water systems and its ease of detection and measurement. A main item of interest in the initial work was to determine the mechanics of flow of an injected chemical in the new well completion set up. The ease of detection and measurement of dichromate was ideal for this work. Sodium hydroxide was injected to determine the possibility of corrosion control through the direct neutralization of acidic well water.

Sodium Dichromate Injection

The results of sodium dichromate injection indicate that excellent corrosion protection is being obtained. With the rate of water production from the wells at Erath, the injection of four to five pounds of sodium dichromate dihydrate is sufficient to maintain 500 to 1000 PPM CrO_4 in the produced water. Experience has shown that it is best to start treatment by injecting 20 pounds of dichromate in 10 gallons of water per day, until returns are obtained, and then cut back to five pounds, which is believed to be the amount required for protection. The first 75 to 100 pounds of chemical cannot be accounted for in the produced water; but after chemical returns are established, the amount of dichromate in the produced water is substantially the amount injected. The following table gives the record for the first few days of dichromate injection in Well 32-1. These results are typical for dichromate injection at Erath.

Time Days	Lbs. $Na_2Cr_2O_7$ $2H_2O$ Pumped	PPM CrO_4 In Produced Water	PPM Fe In Produced Water
1.....	20	0	152
2.....	10	0	155
3.....	20	0	150
4.....	10	0	110
5.....	10	0	40
6.....	5	603	Less than 5

This rate of injection was continued at five pounds per day, and the returns were obtained accordingly.

There are eight wells in the field into which dichromate is being injected at the present time. Injection of dichromate is varied to maintain a residual CrO_4 value of 500 to 1000 PPM. At this rate of injection, the iron content of the produced water is maintained at less than 5 PPM; and there has been no sign of appreciable amounts of reduced chromium compounds in the water. Corrosion rates as shown by coupon tests show a reduction of 88 percent or better (see Figure 4).

Well 33-2 producing from the 10,400-foot zone was worked over and put back on flow May 25, 1945. On July 22, 1945, sodium dichromate injection was begun and has been continued to date. Internal tubing caliper surveys on this well were made on June 11 and October 30 from zero to 3000 feet, and on February 15 from zero to 5000 feet. The record of June 11 was run to obtain a comparison record in order that the later records could be interpreted properly. When the three records

were compared, apparently no evidence of corrosion was found.

Sodium Hydroxide Injection

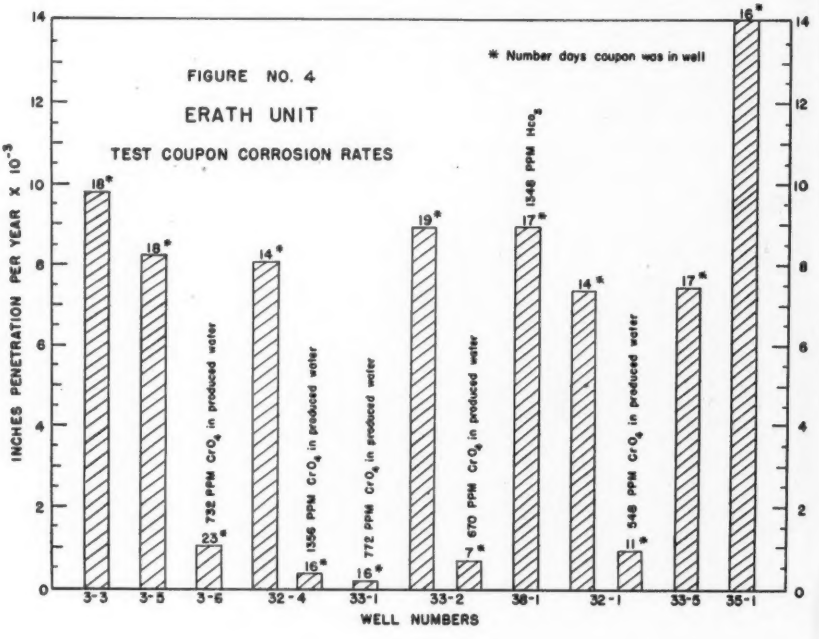
Sodium hydroxide injection in Well 38-1, producing from the 10,400-foot zone, was begun on October 25 to determine the effectiveness of such a strong neutralizing agent as a corrosion inhibitor. The initial rate of injection was one pound per day of caustic in a 10-gallon aqueous solution. The rate of injection was increased by increments up to a value of 10 pounds per day. The results obtained were very erratic; the iron content values in the produced water varying over a range of 15 to 110 PPM (original untreated 120 PPM); bicarbonate values had a range of 1200 to 5000 PPM; and the pH varied from 6.0 to 9.0.

A test coupon was inserted in the well-head flow stream to establish the corrosion rate with caustic injection. The coupon had a corrosion rate of 0.00888-inch per year, which is approximately the same rate as obtained in an untreated well.

Caustic injection has been discontinued in this well and dichromate is now being used.

Corrosion Protection Other than Chemical Injection

In an effort to reduce the localization of corrosion near the collars, possibly caused by turbulence and variations in grain structure, the standard 8-round upset tubing is being replaced with internally flush, fully normalized tubing as the wells are worked over. The tubing weight and composition is also being changed



to 10.2-pound J-55 in place of the 9.3-pound N-80 tubing previously used, because inspection tests have indicated that the N-80 tubing has generally corroded faster than the J-55.

The present plan at Erath is to treat all of the worked-over wells except one—Well (3-5). This well is to be allowed to flow without chemical treatment in an effort to discover the advantages, if any, of using the internal flush, fully normalized 10.2-pound J-55 tubing. A recent caliper survey on this well indicated that corrosion had started in the tubing string. A tubing caliper survey on this well will be run every three months as a means of checking the rate of corrosion. If the tubing begins corroding too rapidly, then chemical injection will be started.

Stainless steel, bronze-lined and weld-lined valves are also being tested in the field, but have not been in service for a sufficient period of time to be reported upon.

Summary and Conclusions

Data obtained to date in the Erath Field indicate that sodium dichromate is an effective corrosion inhibitor. This conclusion is based upon the correlation obtained by iron reduction in the produced water, coupon exposure tests, and caliper surveys.

The iron content has been held to less than 5 PPM when the orange color of the dichromate is apparent. Dichromate injection rates of four to five pounds per day in a 10-gallon solution have been found to be sufficient to maintain chromate residuals in the produced water of 500 to 1000 PPM.

Caliper surveys have shown that in the case of dichromate treatment over a period of seven months there is no corrosion evident. Caliper surveys have shown good correlation with visual inspection of tubing.

Coupon tests in each case of dichromate injection have shown a very great reduction in corrosion rate. These reductions have varied from 88 percent to 96 percent. Coupon tests have shown corrosion rates as high as 0.01511-inch penetration per year in an untreated well. Corrosion rates as high as 0.009-inch penetration per year in the absence of dichromate treatment have been reduced to 0.0007-inch penetration per year with dichromate injection.

At this time the use of sodium hydroxide as an inhibitor does not appear to be practical at Erath. Coupon tests have shown that a perceptible retardation of corrosion has not taken place with injections of caustic in volumes as high as 10 pounds per day. Water analysis results have been exceedingly erratic.

The possibility of reducing corrosion rates and localized pitting by substituting internally flush, fully normalized 10.2-pound J-55 tubing for 8-round upset N-80 tubing is being investigated, but no conclusive data have been obtained as yet.

Work on corrosion control in Erath Field is still in its preliminary stages. Considerable data will be obtained in the near future for a clearer picture on corrosion in an untreated and treated condition. Inspection of well-head fittings and flow lines will be made to show the possibility of protection by dichromate treatment.

As part of the NGAA research

program, an extensive survey of film characteristics on exposed coupons in a corrosive flow stream with and without chromate treatment at Erath is to be made by Dr. Norman Hackerman of the University of Texas. The results of this test may determine the possibility of localized pitting from dichromate treatment.

Work is to be continued through close coöperation with the NGAA, NACE, and API Committees, in addition to extensive coupon exposure tests and the use of other promising inhibitors for a better control of corrosion in condensate wells.

Acknowledgement

Appreciation is expressed to the Erath unit personnel, particularly Messrs. W. A. Grant, E. T. Lincoln, L. R. Oliver, C. F. Redmon, C. B. Scotty, and A. B. Wardlaw, who directed and performed the field work and wrote the reports from which this paper has been prepared.

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View of the first All-Corrosion Exhibition, held at Kansas City concurrently with the 1946 Annual Meeting of N.A.C.E. Taken from the northwest corner of the Arena of the Municipal Auditorium. The camera was unable to include many of the interesting Exhibits which faced the west.

Corrosion in the Water Industry

By H. Arthur Price
Assistant Specification Engineer, Department of Water & Power, City of Los Angeles, Los Angeles, Calif.

OUR SYMPOSIUM is concerned with the corrosion problems in the water works field. In this field, comprising billions of dollars invested principally in ferrous metals, is found perhaps the maximum interest in corrosion protection.

This interest is growing at an accelerated rate as new materials and methods are becoming available for proper protection, and it is hoped that by pooling our ideas at this and subsequent conventions, together with the publishing of papers in the magazine CORROSION, that a store of information will be made available.

The materials utilized in water systems are below ground and are subject to two hazards—internal and external corrosion—as distinguished from the oil and gas industry, where the problem is principally external corrosion.

I should like to tell of some of the problems in the water works field, how they have been corrected, and some of the practices of the Department of Water & Power in Los Angeles.

Water Meter Corrosion

The problem of corrosion in water meters has always demanded much study and research during the development and refinement of the water meter.

Early in the development and manufacture of water meters, it became apparent that non-ferrous materials were essential in the construction of the various component parts of a water meter, and today we find water meters in general made of various bronze compositions.

Although gear trains in the meters were made of a bronze composition in the early stages of meter development and use, still it was found that corrosion at this point was a prominent factor in the breakdown of this important part of the water meter. This was effectively overcome by housing properly the train gears to eliminate their direct contact with water. The application of grease or oil was made to keep all working parts of this unit coated with a long-life film of protective lubricant. The addition of a lubricant in the train-gear housing has increased the life and usefulness of the train gears from five to 10 times their original life in service.

Similarly, the development of special bronze alloys for use in the manufacture of register plates, gearing and spindles, and the bushing of spindle bearings has, in most instances, eliminated corrosion of the moving parts within a register.

One of the most perplexing corrosion problems of long standing encountered in the water meter has been the development of various types of corrosion within the meas-

uring chamber, which, in many cases, have been so severe as to cause a material decline in the operation, and subsequent registration accuracy, of the meter. Other reasons for the heavy toll in the operational efficiency of a water meter, when corrosion occurs within the measuring chamber, are the close fit and tolerances found at this particular point in the meter, and the sensitiveness of the disc operation where these close tolerances have been affected or altered by the development of corrosion.

Many different bronze alloys have been tested. Special, zinc, copper and plastic coatings have been tried in the quest for the most positive means to discourage corrosion development in the measuring chamber. At present the trend is towards the elimination of all veneer coatings on machined interior surfaces of the measuring chamber. The measuring chamber is manufactured of a bronze composition slightly different from that of the main casings. To prevent corrosion, a zinc anti-corrosion ring is placed on the sediment ring on top of the measuring chamber; or the corrosion ring may be cast as an integral part of the sediment ring. The presence of this zinc anti-corrosion ring in the meters eliminates the necessity for the measuring chamber to give up a portion of its zinc from the interior surface, as the dezincification is centralized at the anti-corrosion ring. It has been found that the zinc anti-corrosion ring materially aids in the rapid development of a mineral coating on the interior surface of the measuring chamber, which makes this machined surface less susceptible to all forms of corrosion, with no apparent detrimental effects.

Utilization of copper water tubing has solved the corrosion problem for service lines running from the street main to the meter on the consumers' property. Out of 330,000 services in the Department of Water & Power of the City of Los Angeles, approximately 110,000 are of copper tubing. To date there have been only four failures. Two of the failures were evidently due to a chlorine bubble inside the pipe; the other two were due to ground currents.

Cavitation

A problem closely allied to corrosion, and one which should be considered jointly with corrosion, is cavitation, inasmuch as the proper selection of materials for both is involved. I should like briefly to describe cavitation.

Under rapid flow conditions vacuum pockets occur in valves at points of sharp changes in cross section and on the suction side of turbine runners and pump impellers, all resulting in pitting or eroding of the metal. I have seen the bodies of small throttling valves eaten through in eight weeks, and some large valves eaten through within a year. For many years cavitation was believed to be a chemical action, but is now considered mechanical due to the rapid formation and collapse of the vacuum pockets, causing an eating away or eroding of the metal.

Considerable work has been done on this subject, and I would like to refer to research work by Logan Kerr, Consulting Engineer of Philadelphia, published in the A.S.M.E. Transactions, 1937. Mr. Kerr, in making studies of the proper selec-

tion of metals for both corrosion and cavitation of hydraulic equipment for the Passamaquoddy Project proposed to be built some year ago, performed a series of tests on 85 different metals under both fresh water and sea water conditions.

The conclusions reached were that for non-ferrous metals, manganese bronze and aluminum bronze offer the best wear against cavitation. For ferrous metals, chromium nickel steels offer the best wear against cavitation.

An investigation has been in progress in our Department of Water and Power since 1943, to determine the effectiveness of liners for sections of water pipelines immediately downstream from gate valves used for throttling purposes. Many instances of severe cavitation have been observed. It was thought that linings of a soft plastic material such as lead might be less subject to cavitation. It was decided also to experiment with mortar linings. The tests are being made at one of our reservoirs where a continuous flow of water is available, and where there is a pressure of approximately 175 psi. Three test specimens, consisting of 4-inch steel nipples, 24 inches long, were prepared and installed downstream from throttled gate valves. At the end of the nipple was a 4 x 1-inch reducer which permitted a 10 psi residual in the nipple. Specimen 1 is lead lined; specimen 2 is bare; and specimen 3 is mortar lined with a 1:1 mix of cement and sand, the sand passing a 14-mesh sieve. Pipe was spun in a lathe for four minutes, the lining was moist cured for six hours and then water-cured until installed. A recent examination indicated that specimen 1, the lead lined, is in good condition; 2, the bare, is tuberculated and pitted throughout the length of the pipe; 3, the mortar-lined pipe, is in good condition and showed no change. We hesitate to draw a conclusion at this point. However, we do feel that lead and cement mortar linings have possibilities in preventing cavitation; and we are continuing our experiment.

Graphitization

In Los Angeles there are four large areas where cast iron pipe, valves and fittings are subject to graphitic corrosion. We would like to review the conditions which we feel cause graphitic corrosion. Grahpitic corrosion of cast iron pipe is a form of electrolytic corrosion, in which the dissimilar crystals within the matrix of the metal form the electrodes of micro-galvanic cell couples. Graphitic corrosion of cast iron is further aggravated by the bacterial decomposition of sulphates and the biochemical action of iron-monging bacteria, such as schizomycetes, spirophyllum, gallionella, leptothrix.

H. A. Knudson, of Oakland East Bay Municipal Utility District, in an interesting paper presented before the Western Chemical Congress in 1939, describes two forms of graphitic corrosion which are termed "direction" and "penetrating." The directional form is a spreading of surface form in which large areas are attacked without local pits of noticeable depth, and a well formed graphitized residue usually remains. The penetrating attacks are ordinarily confined to small areas and lead to puncturing of pipe wall. This form leaves a soft, gray residue con-

taining little or no metallic iron. These two types of graphitic corrosion take their annual toll of cast iron pipe as well as fittings and valves. In our department 20 repair jobs were required in 1937 and 50 in 1945, as a result of graphitic corrosion.

It has been learned, by extensive studies of the problem and through data obtained from tests conducted over a period of years, that the corrosive action of soils conducive to graphitic corrosion of cast iron can be delayed by application of a gunite coating and by surrounding the pipe with a blanket of river sand to isolate the metal from direct contact with the corrosive soil. Use of the sand blanket around gunite-coated, cast-iron pipe has two known actions tending to inhibit graphitic corrosion. The sand blanket tends to filter out solid particles and to equalize the concentration of solutions of soil electrolytes. The Portland cement gunite coating further changes the nature and reduces the corrosivity of soil solutions, before they can penetrate to and come into actual contact with the metal. This is the ideal solution for proper protection, but it is costly.

At the present time, when pressure conditions permit, our department installs asbestos cement pipe for 4, 6, and 8-inch mains in areas subject to graphitic corrosion. The larger mains of cast iron pipe have a blanket of sand placed around them.

Consumers' Complaints

Water utilities are continually receiving complaints from consumers with regard to corrosion of their plumbing. The consumers' plumbing usually has been installed by registered, licensed plumbing contractors in strict conformity with specifications set up by the building codes, and has been passed upon by official inspectors. Yet, failures resulting from internal corrosion of the water pipes occur after surprisingly short periods of service life. The mysterious bugs of "electrolysis" and "bad water" are suggested to consumers by someone (usually the plumber) as the only possible explanation for the trouble. Investigation of such complaints, supplemented with sensitive electrolysis tests and a careful check upon the analyses of water supplied, usually discloses a galvanic electrolysis problem, where dissimilar metals have been used, but improperly connected, to avoid setting up electrolytic cell couples between the dissimilar metals. Copper, brass, galvanized-iron, black-iron, and cast-iron pipe and fittings in various combinations and relative proximities are most frequently the sources of self-generated electrolytic currents causing such failures. It should be brought to the attention of all concerned, including the building and safety departments and their inspectors, that juxtaposition of dissimilar metals in contact with water, or any aqueous solutions, must have provisions made for properly insulating and breaking the continuity of electrical circuits otherwise formed by mutual contact of dissimilar metals with any aqueous solution of electrolytes. The finest quality city waters contain traces of dissolved oxygen and carbon dioxide (air), as well as minute quantities of dissolved mineral salts, which serve as very weak solutions of electrolytes, capa-

ble of forming electrolytic cell couples between dissimilar metals with which they are in mutual contact. Until this problem becomes better understood by the public at large, and until it is brought more clearly to the attention of the writers of building codes and specifications, such complaints of unexplained service failures will continue coming in from distressed consumers. It is a duty of the electrolysis section of a department of water and power, in the interests of good public relations in the public service, to assist in an educational campaign on this subject matter when and if called upon to do so.

Steel Pipe

No mention will be made of steel structures, pipe tanks, etc., as it is felt that this subject will be covered by other papers.

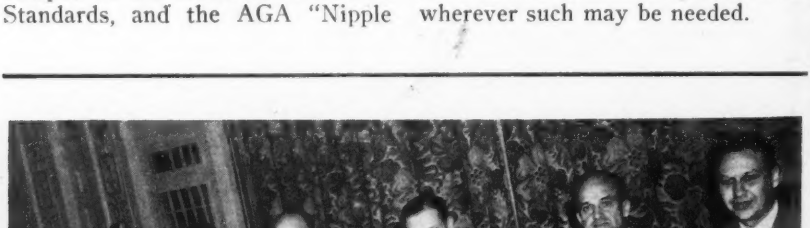
Electrolysis Section—Department of Water & Power

To provide properly for the many problems that occur in regard to corrosion in the Los Angeles Department of Water and Power, an Electrolysis Section was established many years ago. It is now under the direction of R. R. Ashline. The activities of the section include engineering surveys of soil corrosivity, stray current electrolysis, and any and all factors contributing, or tending to contribute, to corrosion of underground pipelines and water works plants. This section is charged further with responsibility for preparing recommendations; for prevention or mitigation of corrosion of metallic structures; with assisiting in the preparation of specifications designed to eliminate and correct existing corrosion hazards; and to avoid those which the engineering surveys indicate may develop if not provided for and protected against. To be effective in accomplishing its purpose, this work involves the coöperative effort of each and all of the several public utility systems operating in Los Angeles and adjacent vicinity. It requires constant vigilance to discover adverse conditions, and to apply effective and economical methods for their control, before serious damage is done to water works plants; without their being detected until serious failures and disruptions to service bring such conditions to light. The application of cathodic protection to pipelines and water storage tanks, in accordance with sound engineering principles and survey data obtained, is also a function of the Electrolysis Section.

Stray current electrolysis surveys are made by measuring, with 24-hour recording smoke charts, the electrical potentials between street-railway tracks and the underground pipelines and cable systems at strategic points; by measuring the magnitude and direction of flow of electrical energy (potential gradients) on substructures; and by comparison of the 24-hour recorded smoke charts with the electric railway load curves, determining the origin of any stray currents detected. Then, knowing the source, magnitude, and direction of stray currents causing electrolysis, it becomes possible to apply effective controls for mitigation of electrolytic corrosion of the water-works plant. The stray current electrolysis surveys made have led to detection, measurement, and segregation of another form of electrolysis known as long-line cur-

rents. These have their origin in the form of electrolytic cell couples between different types of soil areas, through which metallic pipe lines extend and in which they are buried, as distinguished from stray electric railway currents. Long-line currents are self-generated, continuous in their corrosive attack on buried metallic pipe lines, and susceptible to being reduced or eliminated by judicious application of cathodic protection.

Soil corrosivity surveys are made by testing the type and severity of corrosive action of soils, chemically, electrically, and biochemically, upon the structural materials to be buried in them. Of the many tests suggested, tried, and used, two tests have been found more practicable and reliable than the others. These tests have become generally standardized locally and throughout the country. These are the Shepard rod earth resistivity measurements developed at the National Bureau of Standards, and the AGA "Nipple and Can" tests developed and sponsored by the American Gas Association. Several other tests have their special merits, such as the Dennison Cell developed at the National Bureau of Standards. But other tests have not yet become as completely standardized and well correlated with actual corrosion experience on the Pacific Coast. They have not been found as practicable and universal in application to local conditions as the first two tests mentioned. Using the data on soil corrosivity obtained with the Shepard rod tests and the AGA "Nipple and Can" tests, cartograms are prepared for the routes of proposed pipelines, showing the types of soil to be transversed, the indicated soil corrosivity from point-to-point along the route of survey, electric railway crossings, and any other conditions or features which might contribute to corrosion of underground pipe lines, together with notations and recommendations for protection wherever such may be needed.



The Speakers' table at the Buffet Supper, held May 7th in the Ball Room of the Hotel President. From the left: L. A. Baldwin, Chairman, Exhibits Committee; Paul W. Bachman; Dr. H. A. Hass, of Purdue University, the speaker; R. A. Brannon, retiring president of N.A.C.E.; F. J. McElhatton, incoming president; O. C. Mudd, treasurer; Glen W. King, Co-chairman, Cocktail Hour Committee.

Some Corrosion Problems Encountered in Steam Plant Operations

By J. A. Keeth
Manager of Power Production
Kansas City Power & Light Company, Kansas City, Missouri

PROBABLY no single factor plays a more important part in the long array of problems which continually face the power-plant operator than that of corrosion. However, too often is it partially or completely ignored until some forced outage or interruption drives home the full weight of its potency. It is like a parasite, constantly on the alert for a place to strike. Only through a thorough knowledge of its forms and habits can it be kept under control. It seems that one corrosion problem is no sooner solved than some changing operating condition, or some new and presumably improved type of equipment, brings forth another. The corrosion as encountered in power plants takes on many forms, some of which are readily identifiable, while others are obscure and in some cases little understood. The power industry, along with many other industries, is constantly carrying on investigations and research to the end that longer life of equipment be secured and that the physical welfare of those working with and around the equipment be safeguarded.

Rust and corrosion, such as occurs to unprotected metal parts exposed to the elements, while of great importance and the source of much expense, will be excluded from this discussion. We will deal principally with the more troublesome problems possibly not so common to all industries, but those forms particularly prevalent in power plants. From a power-plant man's point of view, it would be easier to classify the equipment particularly subject to corrosion of one form or another than to classify the types of corrosion evidencing themselves in plant operation. However, since this is a paper to emphasize the types of corrosion rather than the equipment affected, an effort will be made to follow the latter procedure.

Table 1 shows six general types of corrosion more or less common in power plants, and below each is listed some of the specific cases encountered. Item 7 is headed "Miscellaneous" and is a catch-all to cover a few divergent types not at all uncommon. Many of the types are not entirely distinctive, but because of the nature of their occurrence, it seems advisable to deal with them as separate and distinct types. In other words, there is some overlapping of fundamentals involved. It is the author's purpose to describe, in some detail, the actual result of these different forms of corrosion as applied to the equipment listed, to touch lightly on the theory of the explanation of the phenomena, and

to describe some of the preventive means. In some types of corrosion, the cause and mechanics of the process is relatively simple, while in others the cause and actual procedure is quite obscure; and even the theories on the cause become too involved for the average power-plant operator to understand. While a basic knowledge of the underlying cause and method by which it progresses is invaluable and often points the way to the cure, many cures have resulted from the "cut and try method." Usually an underlying knowledge of the probable sources of corrosion will prompt preventive measures, and will reduce materially the number of such problems actually encountered in power plant operation.

The discussion of the type will be taken up in the order listed in Table 1.

Table I

1. Attack by Gases Dissolved or Entrained in Liquids. Specific cases:
   (a). Pitting of Boiler and Economizer Drums and Tubes.
   (b). Pitting and General Corrosion of Steel Pipe Lines (internal).
   (c). Pitting and General Corrosion of Condenser Tubes (also Evaporator and Heat Exchanger Tubes).
2. Corrosion Due to Decomposition of Steam.
   (a). Furnace Waterwall Tubes.
   (b). Boiler Tubes.
3. Attack by Stack Gases.
   (a). Air Preheater and Economizer Surfaces.
   (b). Smoke Stacks and Flues.
4. Furnace Slag Attack.
   (a). Waterwall Tubes.
5. Corrosion Fatigue.
   (a). Economizer Tubes.
   (b). Boiler Drums.
6. Corrosion - Erosion.
   (a). Boiler Feed Pump Casings.
   (b). Joints in Turbine Casings.
7. Miscellaneous.
   (a). Graphite Corrosion.
   (b). Copper Plating of Steel.
   (c). Corrosive Liquids.
   (d). Electrochemical.
   (e). Caustic Embrittlement.

1. Attack by Gases Dissolved or Entrained in Liquids

Corrosion caused by dissolved or entrained gases is perhaps one of the most common forms of corrosion encountered in steam power-plant operation. If this statement is not strictly true today, it is because its effect is so well known and its cure definitely established. Oxygen and carbon-dioxide dissolved in water are the primary corrosive agents, although occasionally other entrained gases are the cause, as will be mentioned later. While practically all natural water contains large amounts of entrained air or carbon-dioxide, it is ordinarily not particularly destructive to tanks or pipe lines carrying the gaseous solutions, as long as conditions are such as to maintain the solubility of the gas or gases in the liquid, and where the water carrying the gases contains fair amounts of solids in solution, as in most of our city water supplies. However, dissolved gases, in practically pure condensate and under conditions where the gases tend to be released due to chemical reactions or to increase in temperature of the liquid, become active agents for corrosion.

This form of attack is most prevalent on steel surfaces exposed to the liquid and gas mixtures usually under elevated temperatures. The attack takes the form of either general corrosion or pitting. While the latter form is most troublesome because of its concentrated nature, the two

forms usually are found together. If the attack is the result of dissolved oxygen, then the ultimate products of corrosion are either ferric oxide or magnetic oxide, the latter being common where the metal temperatures are high.

(a). *Pitting of Boiler and Economizer Drums and Tubes.*

This type of corrosion has evidenced itself most in steel tube economizers and the pressure parts connected with them. In boiler installations using steel economizers, the corrosion usually concentrates in the economizer, leaving the internal boiler surfaces relatively free. The pH value of the water in the boiler is usually much higher than in the economizer and as a result the attack is greatly reduced. Furthermore, much of the oxygen in the boiler is carried over with the steam. Therefore, it is not available for attack on the boiler internals.

Mention was made of CO_2 attack as well as oxygen. This occurs in much the same way, but generally is not as common as the oxygen attack. The chemistry is, of course, different, the attack being due to carbonic acid, and the products of the corrosion being ferrous or ferric carbonates in combination with other impurities which may be present in the water.

The recognized cure for this type of gaseous attack is the almost complete deaeration or degasification of the water. This is usually accomplished by some form of deaerator, most types of which work on the principle that the solubility of air or CO_2 drops off rapidly as the liquid temperature rises. For example, the solubility of oxygen in water at 70°F. is 6.2 cc per liter, while the solubility at 212°F. and atmospheric pressure is 0.0 cc per liter. The deaerators must provide means for prompt separation and removal of the released gases. There are many forms of deaerators in use, some operating at atmospheric pressure, others below and still others above. However, all work on the principle of bringing the water to the boiling point for the pressure involved, flashing it, and removing the non-condensable vapors. Standard guarantees on such equipment run around 0.03 cc per liter, which is usually adequate to prevent this type of corrosion on subsequent metal surfaces. A higher degree of deaeration is possible where required. However, it is much more essential to maintain constantly a reasonable value, such as 0.03 cc per liter, than it is to maintain unusually high deaeration, say 0.01 cc per liter, with occasional periods with 0.1 cc per liter, even though those periods are short and somewhat infrequent .

Corrosion on interior economizer surfaces is often reduced by re-circulation of some of the boiler blowdown. This has the effect of raising the pH value of the water, which is a definite deterrent of such corrosion.

In many plants where the maintaining of a uniformly low oxygen content-water by deaeration is difficult, or where it is felt that all traces of oxygen must be kept out of the system, sodium sulphite is added to the water, so as to maintain a measurable excess in the boiler water. This material is a chemical with a remarkable affinity for oxygen. It unites with the residual oxygen, forming sulphates which do not attack the metal. Furthermore, the

material appears to be stable in boilers operating with water temperatures up to at least 450° F. and possibly higher. Frequently the sulphite is added to the water at the condenser, so as to provide protection for the pipelines and equipment between the condenser and the boiler. Whether this has been an unmitigated benefit is not yet certain, as will be mentioned later under another form of corrosion.

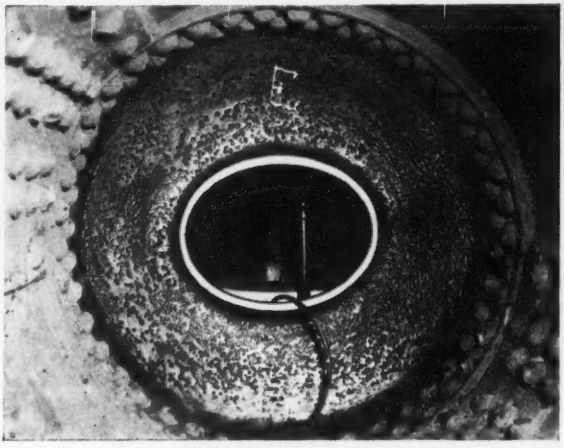


Figure 1—Oxygen attack on steel economizer drum.

Certainly protective metal coatings deserve some mention in this connection. There are many paints and metal coatings on the market described as being cures in varying degrees. While paints are undoubtedly effective against rust and corrosion, when applied to metal under atmospheric conditions, the problem becomes much more difficult when those metal surfaces are submerged and under high temperature. There are a few paints which, if properly applied, undoubtedly afford a measure of protection to the metal against this form of attack. However, it is generally conceded poor practice to depend solely upon that protection, as sooner or later it may lead to trouble—usually sooner. Probably the suitable paints do have a definite field in adding some protection during the periods of poor control of deaeration.

Figure 1 shows the effect of oxygen attack on the internal surface of a steel economizer drum, operating at about 275° F. It is probable that most of this attack occurred with an oxygen content of 0.5 cc per liter, and was the cause for the installation of deaerating heaters to reduce this content to 0.03 cc per liter, which has been effective in arresting the corrosion.

Figure 2 shows the same form of attack on the internal surface of a steel economizer tube. These pits develop remarkably fast in the presence of high-oxygen water and frequently result in holes entirely through heavy wall steel tubes.

It is obvious that such forms of dissolved gas attack are very destructive and unless arrested will result in extremely heavy maintenance, such as is involved in the replacement of economizer drums, boiler drums (where no economizer is used) and steel tubes. The cost of deaeration is almost invariably justified.

(b). *Pitting and General Corrosion of Steel Pipe Lines Carrying Water With Dissolved Gases.*

Under specific cases of this general type of corrosion, shown in Table 1, is that of steel pipe lines carrying water, particularly condensate, with dissolved gases. The attack is much the same as in the economizers and boilers, but usually proceeds at a much lower rate due to lower temperatures prevailing. The same method of prevention can be applied, namely deaeration or treatment with sulphite.

(c). *Pitting and Corrosion of Condenser Tubes.*

Another type of corrosion which might be placed in this general category is that which results in attack on the steam side of brass and copper tubes of heaters and condensers, as a result of ammonia present in the steam and subsequently in the condensate.

While many power plants have escaped this form of trouble, others have run into serious difficulty with it. The relative amount of NH_3 in the various waters used for boiler make-up is largely the answer for the difference in experience, although the design of the equipment also has a definite bearing on the subject.

The corrosion from this cause usually has been most troublesome on the steam side of condensers, heat exchanger and evaporator tubes. The attack is in the form of a general corrosion of the tubes, usually adjacent to the tube sheets and support plates. Microscopic examination shows intercrystalline penetration or attack of the grain boundaries. Usually no products of corrosion are found on metal surfaces due to the high solubility of these products. These products are probably cupric ammonium compounds.

In many cases, tube failures due to breakage occur long before the corrosion has progressed very far into the metal. This is the result of corrosion fatigue. Condenser and heater tubes are usually subject to certain cyclic stresses due to temperature changes and, in some cases, vibration. The damage to the metal as a result of the changing stresses is intensified by the presence of the corrosive atmosphere or solution. The penetration of the corrosion lessens the fatigue resistance of the metal.

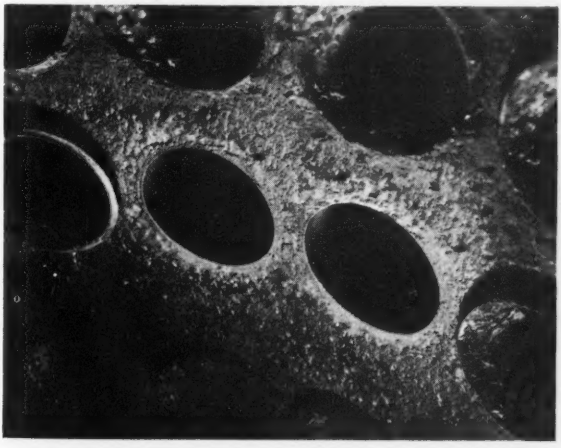


Figure 2—Oxygen attack on inside of steel economizer tube.

There are several remedies, or partial remedies, to the problem of ammonia

attack. The first and most obvious, but usually the most difficult to accomplish, is the removal of the ammonia from the make-up water used in the plant. There are both mechanical and chemical degasifiers made, but their cost is high and may in some cases prove more costly than the periodic replacement of corroded material. Experience has indicated that the design of the condenser, with particular reference to the steam flow and non-condensable gas removal, has a very definite bearing on this form of corrosion. For instance, in one plant there were several condensers all taking steam from the same source. Only one of these condensers was subject to the type of corrosion described. This particular one was so designed that the steam entered the bottom, leaving the upper bank of tubes in a more or less dry state, where such water as was present probably absorbed a large percentage of the NH_3, and produced a concentrated attack on the tubes where it drained down over the tube sheets and support plates. Provision for better penetration of steam in the tube bank and better arrangement for removal of the non-condensable vapors relieved the situation. Furthermore, the use of a different tube material contributed to the solution. High copper alloys, such as red brass and arsenical copper, are particularly subject to ammonia attack, whereas stainless steel and inhibited Admiralties are quite effective in resisting the attack.

It has been found that where ammonia is present in boiler make-up water there is a tendency for it to concentrate in the drainage from the vent condensers of hot-process water treating systems and deaerators, and also from the after-condenser drains on steam-jet air pumps used on condensers. Many operators have found it good practice to discharge the drains from these sources to the sewer instead of returning them to the system. This simple expedient has in several cases lowered the ammonia content of the system to the point where all attack has ceased.

The preceding has described the effect of dissolved ammonia on the steam side of condensers, heaters, and other types of power plant equipment. Ammonia present in the circulating water, if in sufficient concentration, may prove destructive to the water side of condenser tubes. Usually here the only cure is to use a tube material that will effectively withstand the attack. The material to be used is dependent largely upon the concentration of ammonia present in the water. Where circulating water does contain ammonia in appreciable quantities, condensers must be kept absolutely tight so as to prevent contamination of the condensate through leakage, as this will in turn promote the corrosion on the steam side of the tubes as before explained.

2. Corrosion Due to Decomposition of Steam

Corrosion due to decomposition of steam is a form of corrosion occurring largely in boilers and water-cooled furnaces. It was of relatively little concern years ago, inasmuch as boilers were not equipped with waterwalls and were seldom operated at extremely high temperatures, or at high rates of heat release. However, with the advent of higher steam temperatures and higher rates of

combustion, this form of corrosion became a factor of considerable importance. It is seldom found to any appreciable extent in boilers or waterwalls where water circulation is good and where local concentration of extreme heat is avoided. With the rapid development of larger and larger boilers with extremely high heat absorption rates, particularly in the furnace walls, much trouble of this nature developed, until a better understanding of boiler circulation principles was obtained.

(a). *Furnace Waterwall Tubes.*

Many boiler and water-cooled furnaces were installed with points of sluggish circulation. If this slow circulation happened to be at a point of high heat application, the metal temperatures reached a point where in contact with the water-steam mixture on the inside of the tubes there actually occurred a partial decomposition of the steam into hydrogen and oxygen. It will be recalled that one of the methods of producing hydrogen is by passing steam over highly heated iron. The oxygen in the steam combines readily with the iron to produce usually magnetic iron oxide (Fe_3O_4) and free hydrogen. This is exactly the reaction that takes place in an overheated tube containing a steam and water mixture. The steel of the tube is not only destroyed by the oxidation process; but the free hydrogen is also capable of producing a destructive hydrogen attack which is too involved for discussion in this paper, our principal concern being with the more pertinent oxygen attack. The internal oxidation (usually in form of pits) with magnetic oxide coating decreases the conductivity of the tube, tending to produce further overheating and more rapid formation of the oxide. This accelerated reaction almost invariably results in the rapid failure of the tube. The high internal pressure, along with the weakened condition of the overheated metal, usually causes a complete rupture of the tube.

(b). *Boiler Tubes.*

Many peculiar variations of this type of corrosion occur in power-plant boilers and waterwalls. One of the more common of these types is that known as "grooving." For example, a boiler tube that may be more or less starved of water, due to faulty circulation, will in many cases show a grooving or channeling of the inside surface from end to end, the groove covering that part of the tube exposed to the steam above the water line. Water screen tubes have been known to groove on the side of maximum heat application (usually the top side), particularly when the chemical content of the boiler water was not under proper control. Many of these problems have been most perplexing and annoying, but the solution usually has been found in correcting the water circulation, or changing the nature of the boiler water, or both. Each case is a problem of its own, requiring much study and frequently much experimentation. Manufacturers have learned a great deal in recent years regarding the circulation of water in boilers.

As has been stated, this type of failure is almost invariably accompanied by an overheating of the tube metal. Experience has indicated that, even with heavy wall tubes absorbing heat at a high rate, metal temperatures near the surface need not

be more than 50 to 100 degrees above the saturation temperature of the water within the tubes, if the tubes are clean and the circulation adequate. Thermal couples embedded in the tube surface constitute one of the most effective methods of determining the adequacy of the water circulation, and hence, the susceptibility to attack from decomposition of steam or water.

3. Attack by Stack Gases

Damage and loss through corrosion by stack gases rates high among the maintenance items facing most power plant operators. While this problem has always been common in steam power plants, it came into greater prominence with the use of economizers and air preheaters some 20 to 25 years ago. The reason for this was because use of these pieces of heat recovery equipment resulted frequently in the lowering of the temperatures of stack gases to the dew point, that is, the point at which the corrosive products changed from gaseous to liquid form, wetting and adhering to the metal surfaces. The actual corrosive agent is sulphur in the form of sulphurous or sulphuric acid, the sulphur being originally present to some degree in most fuels. During the process of combustion, this sulphur is changed to sulphur-dioxide, which combines to some degree with the water vapor condensed out of the cooled gases on the heat exchange surfaces. The resulting product is sulphurous acid (H_2SO_3), an unstable corrosive agent which is oxidized to some extent by the excess air present to form sulphuric acid (H_2SO_4). This material is the real agent which causes so much destruction to metal surfaces of economizers and air heaters, as well as to stacks and flues.

(a). *Air Preheaters and Economizers.*

Designers of heat recovery equipment of the type described are aware of the danger and try to avoid it or minimize it by utilizing only sufficient surface so that the gases are cooled to some safe margin above the dew point. The dew point, however, is not definitely fixed. It varies with quantity of sulphur in the fuel and, to some degree, with a number of other factors. Furthermore, almost any boiler installation operates over a fairly wide range in load, so that if the economizers and air preheaters are designed for efficient heat recovery, with an adequate margin between the gas temperature and dew point at the high operating loads, then no margin, or at least inadequate margin, exists at low loads. Thus it appears that the designer

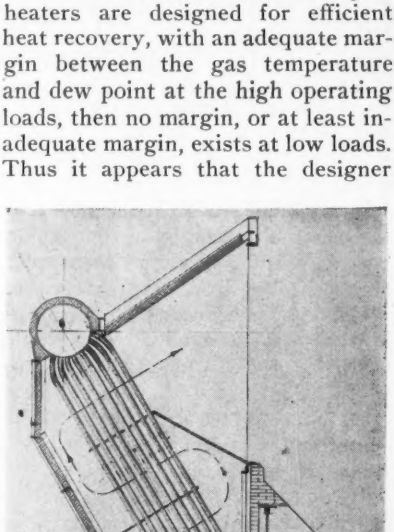


Figure 3—Stirling type economizer.

must make some compromise in efficiency which will provide for protection of the equipment when operating under light loads.

Various means have been devised to permit design of air preheaters for reasonably low gas temperatures at high ratings with a minimum of corrosive attack at light loads. One of these devices is an arrangement for by-passing cold air, thus raising the metal temperature. Another method is to raise the inlet air temperature by recirculating some of the heated air. Also corrosive-resistant metals have been used to some extent. An economizer, however, is not susceptible to the former method of treatment; and the use of corrosive-resistant alloys for construction is too expensive or impractical. Much help can, however, be secured by increasing the temperature of the water entering the economizer. Rarely, if ever, is an economizer in modern practice designed for the low gas temperatures encountered in air preheaters. Hence, generally they are less subject to this type of attack than air preheaters. The author has, however, had experience with at least one serious case of external corrosion of economizers. A description of it may prove of interest.

The economizers in question are of the bent tube two-drum or Stirling type as illustrated in Figure 3. The gases enter the economizer at temperatures ranging from 500°F. to 650°F., make three passes across the tubes, and leave at the upper end at a temperature between 350°F. and 400°F., depending upon the rating of the boiler and the cleanness of the surface. The feedwater enters the lower drum at 220°F. and rises to the top drum where it leaves at a temperature in the neighborhood of 325°F. The water in the economizer is under a pressure of approximately 350 psi.

In this particular case, trouble first developed with leaks in the rolled joints of the tubes in the lower drum. This was followed later with extremely heavy corrosion of the outside surface of the lower two to four inches of the tubes. The gas travel across the tubes was such that a layer of six to eight inches of ash covered the lower economizer drum and served effectively as an insulation, keeping the hot gases away from the lower ends of the tube. The existing soot blowers were ineffective in keeping this ash removed. Two related factors were instrumental in causing the corrosion. In the first place, the lower rolled joints of the tubes were caused to leak by sudden temperature change when water was admitted to the economizer during banks, or when coming off banks. During banks the water in the entire economizer reached a temperature of about 410°F., the saturation temperature at the pressure existing in the economizer. The 220°F. water, periodically admitted during the banked period and when the boiler was brought onto the line after a bank, chilled the rolled tube ends more rapidly than the drum, due to the great difference in metal thickness, and thus loosened the rolled joints sufficiently to permit them to weep. The moisture thus released partially saturated the ash lying on the lower drum. The thick ash layer prevented the hot flue gases from reaching this ash-water mixture to dry it. The wet ash was extremely corrosive and, therefore, destructive to the tube ends. Figure

4 shows the exceedingly heavily corroded end section of one of these tubes. The corrosion progressed invariably until tube failure occurred. Usually failure occurred in three to five years of use.

These economizers have been recently retubed and changes made which it is believed will eliminate the trouble in the future. The corrective measures were as follows:

1. Tube holes were serrated with one groove to increase the holding power and tightness of the roll.

2. After expanding, the tubes were seal welded to the drum and again lightly expanded.

3. A rotating soot blower was installed a short distance above the lower drum so as to permit cleaning the ash off the drum just before going on or off banks. This prevented the accumulation of corrosive ash and the insulation of the drums. The hot flue gases were thus permitted to come in contact with the tube ends, resulting in higher metal temperatures.

4. One-inch auxiliary feed valves were installed in by-passes around the main feed valves so that feedwater could be admitted slowly while on banks, and when coming off banks, to prevent the thermal shock to the tube ends.

While the retubing and corrective measures were effected too recently to have afforded proof of the success of the remedy, there is reason to believe the measure will be effective in preventing a repetition of the trouble.

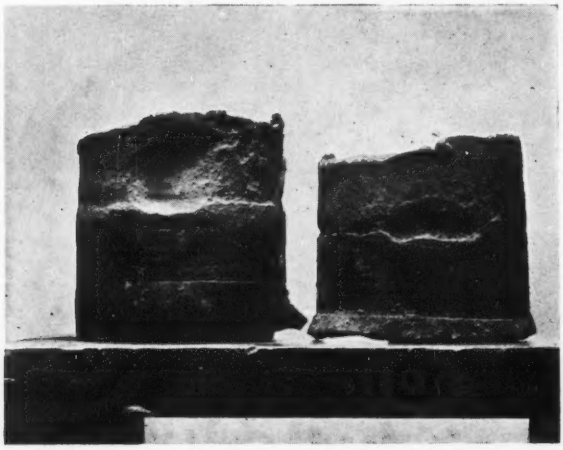


Figure 4. Heavily corroded tube end from Stirling Economizer.

(b). *Stacks and Flues.*

This same type of corrosion is common in steel stacks and flues, particularly where the flue gas temperature entering is at or near the dew point. Stacks and flues are usually uninsulated and, therefore, subject to chilling from cold winds or drafts. Hence, even though the gases may enter at a temperature well above the dew point, temperature of the gases immediately in contact with the cooler metal surfaces

may be lowered sufficiently to reach the dew point, thus permitting the condensation and sulphurous and sulphuric acid on the metal. Under such conditions, the life of stacks and flues may be very short. An effective cure can be obtained by using a gunite lining to the gas ducts and stacks. Experience has shown that where such linings are properly installed, the life of the metal, so far as internal corrosion is concerned, is almost indefinite. Where gunite linings cannot be used, an effective job can be done frequently by insulating the outside of the ducts and stacks to prevent chilling from outside atmosphere. This last scheme presumes, of course, that the temperature of the gases are maintained above the dew point.

4. Furnace Gas and Slag Corrosion

No description of power plant corrosion problems would be complete without at least some mention of that type of attack which has been noted during the past five or six years on the furnace wall tubes in the so-called wet bottom type of pulverized coal-fired furnaces. A complete description of the present state of knowledge of this type of attack would require a paper devoted to this subject alone. Hence, little more than a statement of the phenomenon, and the remedies so far found reasonably effective, can be made here.

This type of corrosion has the appearance of a "washing away" of the surface of the waterwall tubes facing the hot furnace gases. Figure 5 shows a section of a furnace tube that has been so attacked. It is usually confined to the lower four to six feet of the waterwall tubes and in an area more or less adjacent to the pulverized coal burners. The action is frequently very rapid and may result in the "washing away" of ⅛ to ¼ inch of metal in a matter of a few months. Needless to say, this inevitably results in the failure of the tubes, due to the internal pressure. The corrosion is usually connected with two types of deposits, one being a greenish-white enamel, water soluble, containing much iron; the other an insoluble deposit high in iron sulphide and iron oxide. The attack is definitely associated with the molten slag running down the tubes and with a surrounding atmosphere of carbon monoxide. The design, location, and performance of the coal burners has a direct bearing on the corrosion, probably insofar as it is responsible for the atmosphere of carbon monoxide adjacent to the

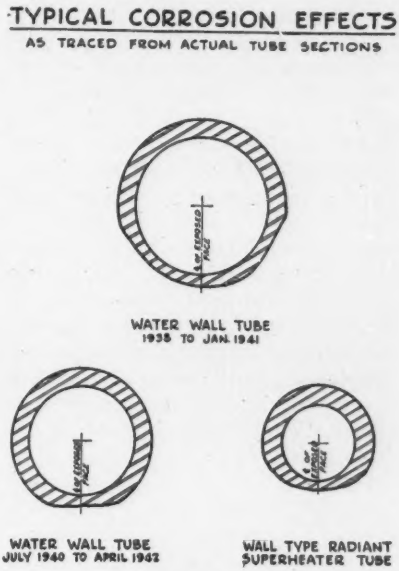


Figure 5. Section of furnace waterwall tube attack by slag.

tubes. Furthermore, the presence of large quantities of sulphur in the fuel appears to be an influencing but not determining factor.

A vast amount of research and study has been given this subject by public utilities, by boiler manufacturers, and by the U. S. Bureau of Mines. The final answer as to the exact chemical and physical nature of the attack is probably not yet available, but enough has been learned so that fairly effective measures are available for use against it. Probably the most effective action consists in the maintenance of an oxidizing, rather than a reducing, atmosphere adjacent to the tubes. This has been obtained through burner improvements and the admission of excess air, sometimes through the burner and in some cases through ports between the wall tubes near the lower end. The latter has not been particularly successful, due to flowing slag soon closing the openings. In general, operation with somewhat lower CO_2 has been helpful. Many different types of coatings and coverings for tubes have been used with varying success. In many cases the welding of studs to the tubes, and packing between and over the studs with special refractories, has been helpful. Few of the special chrome paints or sprayed metals have been effective, although it is at present reported that a coating of sprayed aluminum looks promising.

While it cannot be said definitely at this time that the final answer to this trouble has been found, it is generally sufficiently well controlled by some of the means mentioned that it is no longer of the extremely serious nature it was when first discovered a few years ago.

5. Corrosion Fatigue

Mention has already been made of this form of attack under the heading of "Attack by Gases Entrained in Liquids" — specifically, ammonia attack on condenser and heater tubes. There are several forms in which this is experienced in power plants, many of which could be treated under the general heading of "Attack by Gases Entrained in Liquids." But because the failure of the part can occur with relatively little wastage of the material, it seems preferable to describe these attacks under the heading of "Corrosion Fatigue." In other words, the failure is the result of both stress and corrosion. Equipment parts, subject to cyclic stresses at values at or near the working limit of the material when in the presence of a corrosive agent, usually fail after relatively short periods of exposure to these conditions.

(a). *Corrosion Fatigue in Economizers.*

An outstanding example of corrosion fatigue is the cracking of alternately stressed economizer tubes carrying water containing excessive oxygen. This trouble proved particularly serious in one of the plants with which the author was connected.

The economizers in question formed part of the heat recovery equipment of three 225,000-lb.-per-hour, 700-lb. pressure boilers. These boilers operated during the day periods at ratings varying from 100,000-lb.-per-hour to the maximum given above, but during the night period were usually banked off at practically zero output. The feedwater for the boilers consisted of a

mixture of condensate and treated deaerated make-up, fed to the economizers at about 215°F. Due to certain operating conditions, deaeration was not all that could be desired and at times the oxygen content of the feedwater reached values as high as 0.10 to 0.20 cc. per liter, whereas the average value was usually in the vicinity of 0.02 to 0.04 cc. per liter. The economizers were of such design that the feedwater entered at the top or cool-gas end, progressing downward through parallel rows of horizontal tubes under pressure of the boiler feed pumps to the bottom,

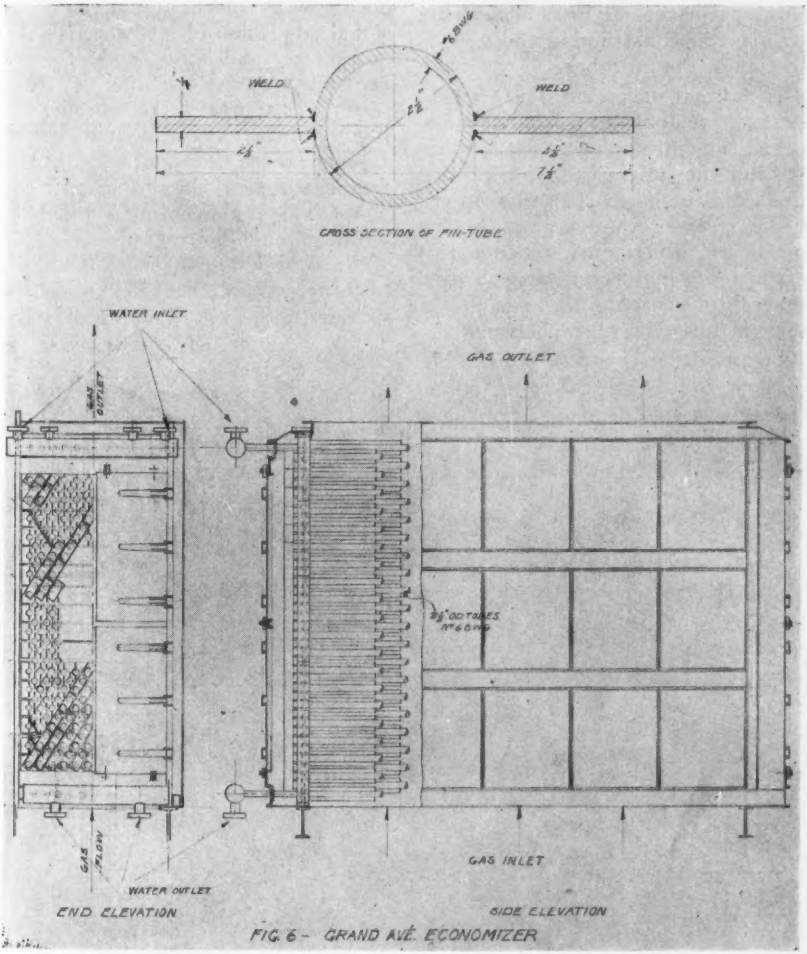


Figure 6—Grand Ave. economizer and fin-tube.

or hot-gas, end from whence it flowed through pipes into the boiler drum.

As mentioned above, the economizer comprised several parallel rows of steel tubes 2½ inches in diameter, with 2¼-inch fins welded on diametrically opposite sides for the purpose of increasing the heat-absorbing surface. Figure 6 shows the economizer construction and a cross section of the fin tubes.

In normal operation, there was a gradual temperature gradient between the extreme outer edge of the fin and the inner wall of the tube, this gradient being such that no unusual stresses were set up in the metal. However, during banks this gradual temperature gradient changed several times each night to an abrupt temperature difference between the tube and the fin, with the result that high cyclic stresses were set up in the tube metal. During the banked period of the boiler, with the feedwater supply shut off, the water in the economizer soon reached the saturation temperature, which in this case was about 500°F. The fins undoubtedly assumed a temperature possibly 50°F. higher at the outer edges, due to the temperature of the surrounding stack gases.

The slight steaming of the boiler during banks necessitated the occasional admission of feedwater to the economizer and boiler, so as to prevent low water. Each time the feedwater was admitted, the tubes on the inlet end of the economizer were rapidly cooled to about 215°F., the temperature of the entering feedwater. This rapid cooling of the tube, with the much more gradual cooling of the extended fins (probably 250°F. temperature difference), set up stresses in the tube wall of approximately 42,500 pounds per square inch, as can be readily calculated. This stress would be added to the stress due to an internal pressure of about 700 pounds per square inch. When this stress occurred in metal partly corroded by the oxygen present in the water, cracks developed. Figure seven is a photograph of one of the numerous failures which occurred in these tubes. The fins had been cut from the specimen photographed. The tube has been split longitudinally, so as to show the circumferential crack which started on the inside, finally progressed until it reached the outer wall, and resulted in

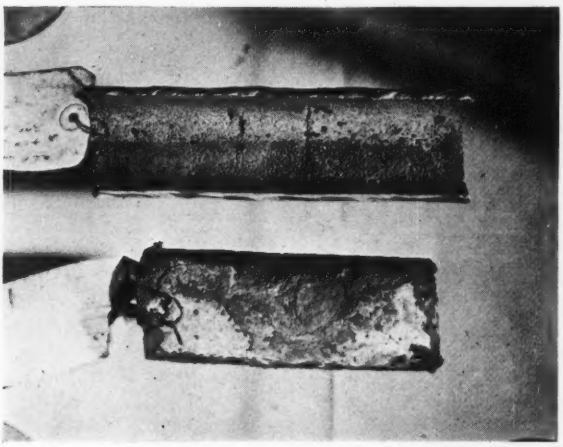


Figure 7—Cracks in Grand Ave. economizer tube.

the complete failure of the tube. Here the repeated reversal of stress under corrosive conditions caused a glaring example of corrosion fatigue failure.

The trouble has been corrected in this installation by retubing the economizers and the modifying of the banking procedure. Small throttling valves were installed in bypasses around the main feed valves, so that a small flow of water could be kept passing through the economizer to prevent the water in the inlet tubes from approaching the saturation temperature, and further to permit gradual increase in water flow through the economizer as the boiler was being brought off the bank for normal operation. In addition to this, better control of deaeration of feedwater was obtained, and sodium sulphite added to absorb any residual oxygen. Thus the two causes for attack were eliminated, namely high alternating temperature stresses and the corrosive agent, oxygen.

(b). *Corrosion Fatigue in Boiler Drums.*

Parts of boiler drums are, likewise, subject to this form of attack. Its results here can prove even more costly. A number of operators of high-pressure boilers have experienced cracking of the inside surface of the drums at the feed line and water column connections. Again, an experience of the author in this connection will serve to describe this type of attack. It occurred in the main steam drum of two 1400 psi boilers. These boilers had forged steel drums, with the lower water column connection brought into the drum radially on the lower side at a point near each end. The connections consisted of 1¼-inch O.D. No. 5 gage tubing, expanded into a counterbored hole, the rolled part of the tube being approximately 1¼-inch in length. The inside part of the tube a hole was counterbored, leaving a fairly large pocket at the end of the lower water column tube connection. The total drum thickness in this case was 5¼ inches

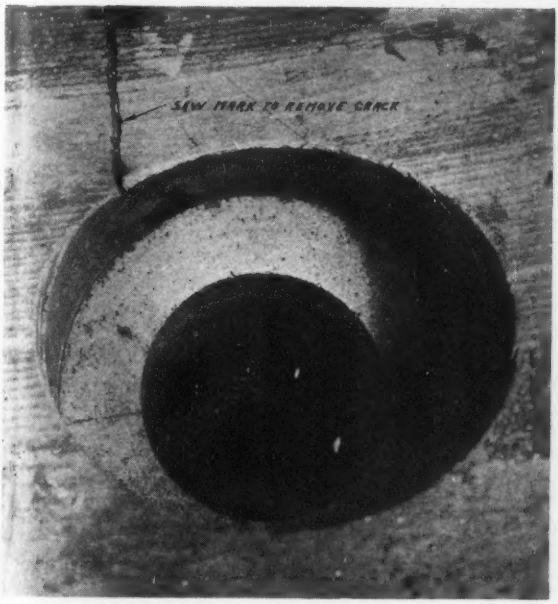


Figure 8—Tube hole for lower water column connection in high pressure boiler drum. (One with saw cut.)

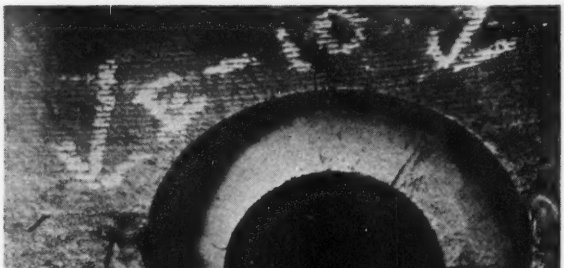


Figure 9—Same as Figure 8, without saw cut.

and the counterbores 2⅜ inches diameter, immediately above the tube roll and 4 inches diameter at the inner drum surface.

Figures 8 and 9 are photographs taken of the counterbore of two of these holes. Both photographs show very distinctly the cracks radiating across the face of the step-off in the counterbore, and also cracks at the top of the large counterbore extending out into the drum. Figure 8 shows the start of a sawcut for the removal of a V-shaped piece to be used for microscopic analysis. The other saw cut was so made as to include the crack shown in the photograph. The investigation made of this attack disclosed that the cracks were transcrystalline, therefore, not in the category of caustic embrittlement. The cracks were definitely of a corrosion fatigue nature, and were undoubtedly the result of the pure condensate coming back from the water columns standing in these large tube counterbores in contact with the drum metal.

This condensed steam returned from the water columns was of very low pH value (6.9 to 7.3) and, therefore, of a corrosive nature. The tube holes were in the ends of the drums beyond the point of circulation, so that little if any dilution of this low pH value water occurred. Tests also showed that the water returned from the water columns was approximately 250° F. lower in temperature than the water in the drum, and hence the main body of the drum metal. This difference in temperature probably set up some temperature strains at the sharp edges of the counterbores, which along with the corrosive action of the water caused the cracks.

Figure 10 shows how the trouble was corrected. First the cracks were bored out by means of a boring rig set up inside the drums. It was believed desirable to eliminate all trace of the cracks so as to prevent points of incipient trouble. The counterbores were enlarged and stepped off as required to remove all cracks, and at the same time to conserve as much of the drum metal as possible. Next the lower water column connections were brought entirely through the drum and over into that portion of the boiler where active circulation existed. The figure shows how these pipes or tubes were extended, using a water-tight tapered joint which did not in any way ef-

fect the tightness of the rolled joint. In addition to carrying the water column discharge over into the active boiler circulation (pH value of boiler water 9.5 to 10.0), water from the tube hole counterbore was caused to flow over to one of the main boiler tubes in which the normal flow was definitely down, thus putting the water in that cavity into active circulation. The cure has been effective, as no further cracking has occurred after several years.

A similar type of cracking of boiler drum metal has occurred where the feedwater is brought into the drums. This has been particularly common in thick drums, where the feed line is studded to the outside of the shell and the internal feed distributing pipe is studded to the inside, thus resulting in the drum itself becoming a portion of the feed line. Where considerable differential exists between the temperatures of the feedwater and the water in the drum, and where the feedwater is of marked purity, corrosion cracks are almost sure to appear in the drum metal acting as a portion of the pipeline. The stresses are set up by the tem-

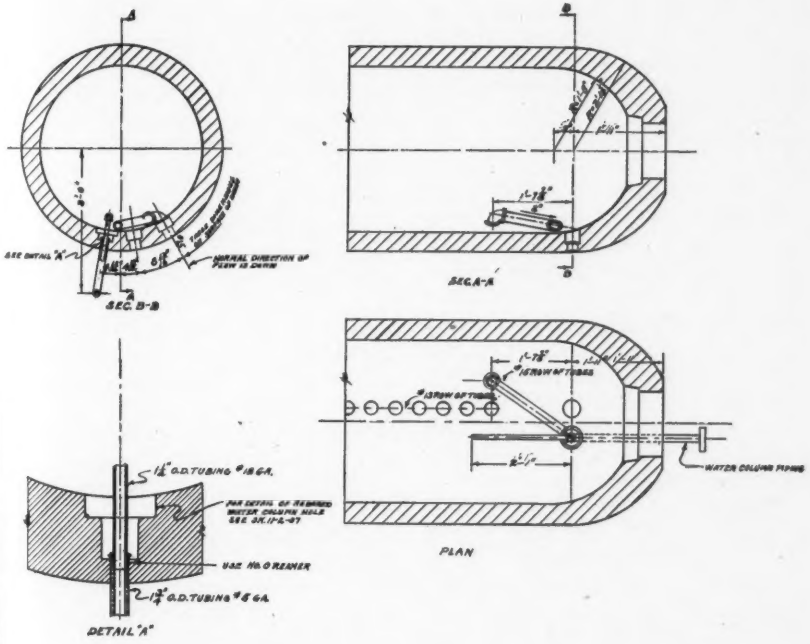


Figure 10—Method for preventing corrosion cracks in water column connections.

perature differences and the feedwater is the active corrosive agent. Where corrosion of this type has occurred, the cure has been effected by conducting the feedwater through a sleeve, where it passes through the drum wall, with space between the sleeve and the hole in the boiler drum for the boiler water to enter. Thus the temperature strains are eliminated, and only boiler water of reasonably high pH value comes in contact with the drum metal.

6. Corrosion Erosion

Within the last four or five years some power plant operators have been confronted with another form of corrosive attack. While it is not a new phenomenon, it appears in a somewhat different guise and has become acute for some inexplicable reason. Evidently, at about the start of World War II, a number of power plants began experiencing rapid loss of head and capacity in their high-pressure boiler-feed pumps. Generally, this was confiined to high speed centrifugal pumps operating at discharge pressures from 1000 to 1800 psi and at temperatures usually above 220°F. Examination of these cases of trouble disclosed severe erosion or corrosion of the inside of the steel pump cases, sometimes accompanied by the same form of attack on the impellers, diffusers and stage pieces, particularly when these parts were made of bronze or steel.

The fact that many of these cases of trouble developed with pumps manufactured during the war led to speculation as to whether substitute materials or poor castings might be the cause. While this may have been a factor in some cases, it began to show up in other instances with pumps which had operated successfully for many years. The whole occurrence proved so erratic that a thorough investigation of the matter was started, not only by individual companies experiencing the trouble, but also by a joint committee of the Edison Electric Institute and the pump manufacturers. While this committee has issued occasional progress reports, neither it nor any of the private investigators claims to have the complete answer, as yet.

It appears definite that the action is a combination of corrosion and erosion. Its action is usually most severe at points of highest water velocity or turbulence. There is, likewise, definite, but not indisputable, evidence that low pH value of the water is an important factor. It has been found that pump interiors coated with the red ferric oxide are less subject to the attack than those coated with the black oxide. In many cases, the attempt to maintain zero oxygen in the water has prompted the use of sodium sulphite. The black oxide coating is most generally found in the pumps where sodium-sulphite is used; hence there are those who believe its use should be avoided in the water passing through the pumps. However, the occurrence of this type of corrosion-erosion in pumps where no sulphite is used proves that the sulphite cannot in itself be the sole cause, even though it may produce a conducive condition.

It has been observed that pumps handling water which has enough scale-forming properties to coat the inside of the pump with brown or reddish scales are usually free from trouble. Generally, the attempt to produce more scale-free waters has

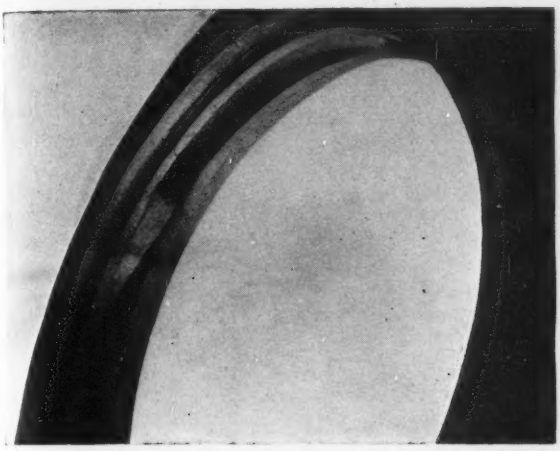


Figure 11—Corrosion-erosion of boiler feed pump diffuser.

resulted in low pH values and has led to the feeling that the pH value of the water is an indicator, at least, of the probability of attack.

The matter of pH value and the temperature of the water pumped are related. Therefore, temperature may play a part. It is a recognized fact that pH value drops as the temperature rises. For example, water with a pH value of 7.2 at 77°F. would probably be about 5.9 at 330° F. It is for this reason that it is believed that the probability of corrosion is greater where the water pumped is hotter, although there are numerous cases of freedom from corrosion with high-temperature water. The author had experience with a case where a pump had operated for more than 50,000 hours, handling water of the above pH at 220°F. without any evidence of corrosion. This was a pump constructed with a cast steel case, with bronze impellers and diffusers, and with steel channel rings. After the above period of operation, the feedwater temperature was increased to about 350°F. with absolutely no other change. During the succeeding period of 1500 to 2000 hours, the capacity and head of the pump fell off rapidly. Inspection disclosed very serious erosion and corrosion of the diffusers and impellers, also the channel rings and casing at the fits. The attack was most severe at the circumferential line of clearance between the outer diameter of the impeller and the diffuser and at the hub wearing rings. A normal clearance of 0.010-015 inches had increased to nearly 0.125 inches. Figure 11 shows the appearance of the worn surfaces of the diffuser. The uneven, "washed away" appearance should be particularly noted. The only attack on the steel casing was at the point of channel ring fits as shown in Figure 12.

A discussion of this case with the manufacturer resulted in the replacement of all internal parts which had been affected (except the casing) with chrome-iron parts. The new impellers and casing wearing rings were .012 percent carbon, 12 percent chromium, while the diffusers, impeller wearing rings, and channel rings were 0.22 carbon, 5½ percent chromium, 0.5 percent molybdenum. This change has been effective in stopping the attack, the pump having operated approximately 12,000 hours since the change at a temperature of 330°F.

While some of the pump manu-

facturers a year or so ago set up charts to show the recommended materials to be used for water of different pH values, these are not entirely in agreement with each other, nor with scattered cases of actual record. For instance, one manufacturer's chart shows bronze or bronze and iron for waters with a pH range from 6.0 to 9.0. The pH value of the water in the particular case cited above was within this range whether taken at 77°F. or at 330°F., yet the bronze and steel parts were severely attacked. Today, it is probably the consensus of opinion of most pump manufacturers that the only safe procedure for high-pressure boiler-feed pumps is the use of chrome iron throughout, even including the case. All evidence to date proves that the presence of 5 percent chrome in the steel is entirely effective. On the other hand, some manufacturers prefer to play even safer and use percentages of chrome as high as 11 to 13 percent. In some instances, the casings are being made of low-carbon steel and lined with chrome iron. Likewise, Monel metal has been found generally satisfactory for impellers, and in some cases, for shafts.

Figure 12—Corrosion-erosion of channel ring fit of boiler feed pump.

While at least one remedy, namely the use of the so-called stainless steels, has been found for this form of erosion-corrosion, there certainly is not too much known about the exact causes. Undoubtedly the investigation will be continued in an effort to clear up the many conflicting conditions under which the attack has been observed. The interest will certainly remain keen until the answers are found.

7. Miscellaneous

Table 1 shows under Item 7 a number of types of corrosion which, as stated before, are not at all uncommon. They have been grouped under the heading of "Miscellaneous," not necessary because they are less important, but because the time limitation for this paper will not permit of detailed treatment of all common forms encountered in power plants. A brief statement regarding the five forms listed under this heading will be all that can be included.

(a). *Graphitization*

This is a form of attack occurring in cast iron. It is most commonly found on the internal surface of cast-iron water-pump and valve parts.

The cast-iron bowls and diffusers of deep-well pumps, operating in water containing considerable oxygen and carbon dioxide, are particularly subject to it and frequently have a life of only a few years. In this attack the iron is largely removed, leaving the carbon with the size and shape of the casting not materially changed. A casting so attacked can be readily whittled away with an ordinary knife. Threads become so weakened that they will no longer hold studs. This is in all probability an electrochemical corrosion wherein the iron is dissolved away, leaving only the carbon or graphite originally present in the iron. Cast iron usually contains three to four percent carbon.

In many cases it is probable that bacteria enters into this form of corrosion. Certain bacilli reduce the sulphates in the water, liberating hydrogen sulphide, which attacks the iron and forms black iron sulphide. The application of a reagent to some graphitized cast iron readily proves the presence of iron sulphide by giving off the distinctive odor of hydrogen sulphide.

In all cases of graphitizing of cast-iron pump parts which have come to the author's attention, the cure has been the replacement of the parts so attacked with bronze. Undoubtedly, some of the stainless irons would be equally effective; but their cost is not warranted where bronze has proved effective. It is believed that the design of ports and passages in pumps, which minimizes the eddies, reduces the rate of attack, as well as does the maintenance of lower water velocities. Usually slow speed, larger diameter pumps are less subject to attack than small, high speed units. This factor of eddies and velocities, as well as some difference in the cast iron itself, may be the principal reason why cast-iron pipe, even that carrying the same water as the attacked pump, is usually free from graphitic corrosion.

(b). *Copper Plating of Boiler Drums and Tubes.*

This is a problem much discussed by power plant operators. While it is very common, there seems to be no positive proof that it is necessarily accompanied by any destructive effects. Frequently large amounts of metallic copper and copper oxides are found in the drums, tubes and waterwall headers of boilers. Undoubtedly the copper comes from a loss of that metal from the condenser tubes, the heater tubes, or the bronze pump parts. Ammonia and carbon dioxide definitely increase the solubility of copper in water, particularly in water of high purity, such as steam condensate. The actual chemical reactions which take place in the solution of copper are none too well known.

Any corrosion which takes place as a result of the deposition of copper on boiler steel is assumed to be electrochemical in nature. Only when the action becomes concentrated in definite spots, as contrasted with uniform distribution over the entire drum, does it become actually dangerous. As stated before, it is a moot question just how serious this form of attack can become. A great deal is yet to be learned about it.

(c). *Corrosive Liquids*

It is frequently necessary in power plant operation to transfer many dif-

ferent forms of chemicals through pipe lines and this requires a thorough knowledge of suitable metals. A number of charts have been published which are a definite aid in selecting the proper or best suited materials. Among the materials frequently handled in power plants could be listed phosphates (several kinds), brine, soda ash, lime water, sodium sulphite, and frequently hydrochloric and sulphuric acids (usually inhibited). The modern treatment of feedwater requires the use of many of these chemicals. Their conveyance through pipelines without a thorough knowledge of their behavior is usually the cause of much grief.

(d). *Electrochemical*

Electrochemical corrosion, of which the copper plating described above and the graphitizing of cast iron are possible examples, is quite common and often somewhat obscure in ultimate theory. It is, however, quite common in power-plant work. It is similar to galvanic action such as is set up where dissimilar metals corrode in aqueous solutions. The current in the corrosion cell leaves the anode carrying with it metal and leaves the solution at the cathode and deposits the metal carried over. The deposited metal may not always be in evidence as it is frequently carried away by the washing action of the solution.

Electrochemical corrosion is not to be confused with electrolysis. In electrolysis, electric currents enter the system from an outside source such as stray ground currents or currents from improperly insulated electrical equipment.

(e). *Caustic Embrittlement*

This type of corrosion has played such a disastrous part in boiler operations in some locations that it cannot be completely overlooked in this paper. However, so much has been published on it, and its prevention so well understood that little space will be given to it here. Caustic-embrittlement is an attack by caustic waters on the grain boundaries of steel. It is definitely an intercrystalline attack on highly stressed steel at points where a concentration of caustic occurs. A common location is the ligament between rivet holes and the rivets themselves in joints of boiler drums. Leakage under rivet heads and butt straps permit a building up of the concentration of caustic which attacks the stressed parts.

The cure usually consists in proper control of the sulphate carbonate ratio of the boiler water and the use of a type of construction which prevents leakage at points of high local stress. Some types of steel have been found to be more resistant to this attack than others, although power plant practice still continues to use the same material.

Conclusion

The author realizes that the description given in this paper on the various forms of corrosion are sketchy and incomplete, and further, that many experts may well take issue with some of the statements made. However, the author has tried diligently to present facts, which in most of the cases are obtained from personal experience and much study of the specific cases with which he has been confronted. It is hoped that the ideas which have been set forth

in this paper will serve to show the broadness and scope of the corrosion problems with which almost every steam plant operator is confronted and further, that they may point the way to prevention for those who have not yet experienced the difficulty.

Many practical remedies have been presented and doubtless there are many other solutions just as effective as those which have been offered. Certainly a good power plant engineer should never permit himself to think that he has encountered and solved all the corrosion problems. New and more difficult ones will follow with every change and improvement in plant design and modification in feed-water treatment. To be constantly alert to these possibilities is one of the most important duties of the power plant engineer and his staff of chemists and research men.

The cover illustration shows the same view as pictured in Figure 12 of this article. It is the steel case and wear rings of a centrifugal pump operating under a working temperature of 330 degrees, Fahr., handling feed water with an estimated pH of around 5.9 at the working temperature. The view shows the points at which corrosion attack was most severe, and indicates areas where leakage would occur through increased clearance between wear rings and rotor as corrosion attack continued.

Installation and Protection of Underground Gas Distribution Systems with Pipe-Line Enamel

By P. D. Mellon

Chief Engineer, The Canadian Western Natural Gas, Light, Heat and Power Co., Ltd., Calgary, Alberta, Canada

THE COMPANIES with whom I am associated in Canada have, during the past 20 years, experimented with or used almost every kind of protective coating on the market. After burying duplicate pipe nipples covered with many different varieties of recommended paints, enamels and coatings for extended periods in highly corrosive soils, as well as carrying out accelerated tests and similar practices followed by other companies, we have for the time being adopted coal tar enamels exclusively as a protective coating for all of our underground steel pipe.

Before proceeding further it might be interesting to those of you who are not familiar with conditions in Western Canada, to relate briefly some statistics pertaining to our major natural gas companies. Although there are a number of communities supplied with natural gas in the Province of Alberta, the cities of Edmonton and Calgary are the two largest centers, and these are the only ones where appreciable quantities of natural gas are consumed. The cities of Lethbridge and Medicine Hat, next in size, are also consumers of natural gas fuel. Edmonton, the capital of Alberta and a city of more than 100,000, is supplied with natural gas by a duplicate transmission line, 125 miles long, from the Kinsella field. Calgary, 200 miles to the south, and a city approximately the same size as Edmonton, draws its main supply of gas from the well-known Turner

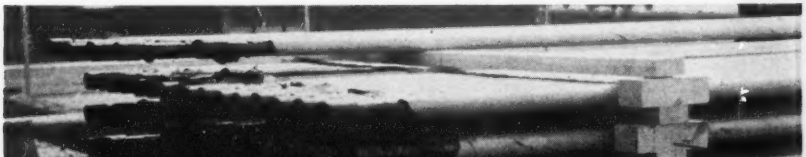


Figure 1—Yard coated pipe ready for installation.

Figure 2—Welding service pipe on job.

Valley field, which is 40 miles away, and during peak loads, from two other fields in the south of the province.

The two companies operate 1,053 miles of underground piping, exclusive of house service connections, supply 48,000 customers and market 23 billion cubic feet of gas annually. The yearly average degree day deficiency below 65°F. in Calgary amounts to 8,886, while peak load deliveries run as high as 93 million cubic feet per day. Innumerable sloughs and lakes are common throughout the central and southern portion of the province, while the soil is highly corrosive with considerable alkali in evidence. Unprotected standard weight steel pipe has an estimated life of only six years through some of this hot soil.

For some time now our company has been intensely interested in the subject of corrosion and has spent considerable sums of money in reconditioning and maintaining our transmission system. Small sections of pipe through hot soil were removed, sand-blasted, pit-welded and thoroughly cleaned, and re-installed after applying the then best protective materials available. We were not entirely satisfied with this procedure and it appeared to be a waste of money. When pipe-line enamels appeared on the market we began to experiment and use these with fair results. Later on, after making a complete soil survey of our entire transmission system, cathodic protection was tried out using zinc anodes. In some cases these anodes were applied to bare pipe and in oth-

ers they were used in conjunction with newly installed enamelled pipe. Investigations and tests carried out since have shown that highly satisfactory results have been obtained with both methods. The merits of applying cathodic protection using an outside source of power have also been considered.

There have been so many interesting papers published on various protective measures for transmission lines that I thought it might be of interest to relate and illustrate some of the methods adopted by our companies, the Canadian Western Natural Gas Company in Calgary and its associate company, the Northwest-

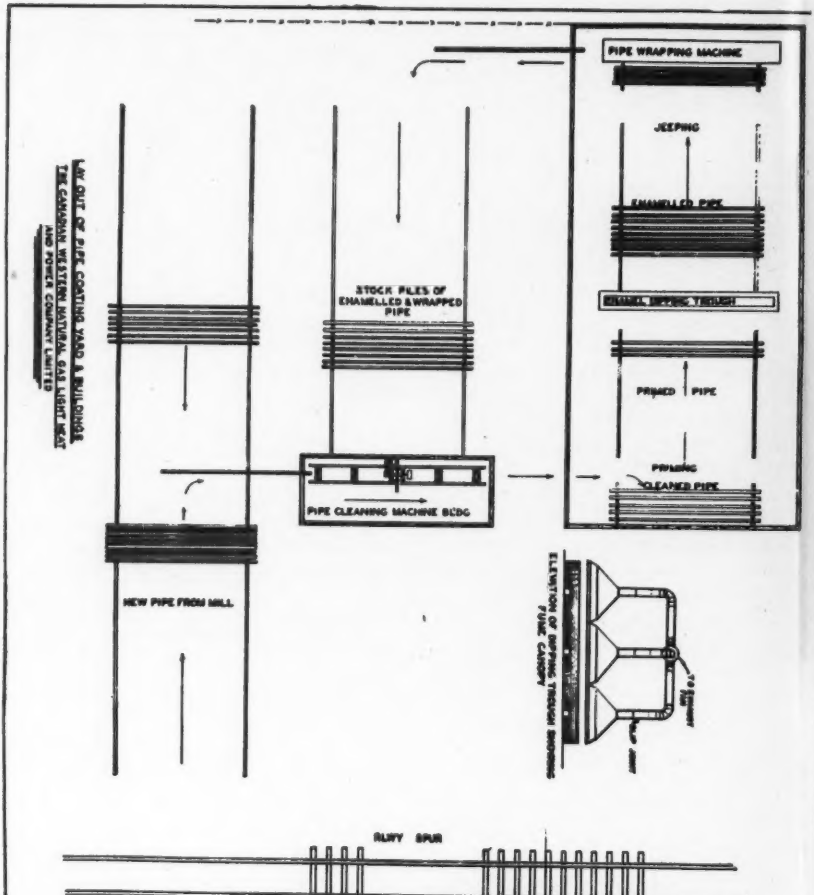


Figure 3—Layout of pipe-coating yard and buildings.

ern Utilities in Edmonton, in preserving underground steel pipe in our distribution plants. Therefore, it is the purpose of this paper to deal mainly with the application of coal tar enamels as used by these companies in the protection of their distribution plants.

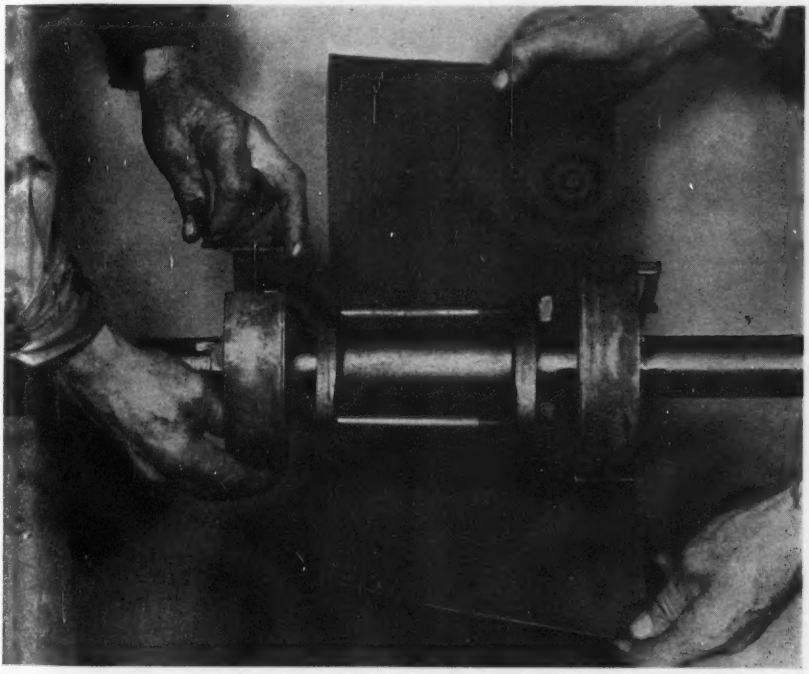


Figure 4—Assembling coating pan for treating small service couplings.

At one time or another most of you have been faced with adjustment in rates which involved a revamping of your amortization or depreciation fund. I believe most of us will agree that a properly installed plant, scientifically protected against corrosion, should have a longer life than a plant installed without such protection. Pipe treated with any of the widely known pipeline coatings on the market, or with a proper cathodic installation, will allow the operator to reduce yearly amortization charges with resultant reduction in operating costs. Further, the installation of thin wall or lighter weight steel pipe, adequately protected, is permissible and should have a life two to three times that of unprotected standard weight bare pipe. The reduction in troublesome and expensive lawsuits, usually the result of excessive gas leakage, is another of many important factors worth considering.

Natural gas companies in Alberta are geographically isolated from all

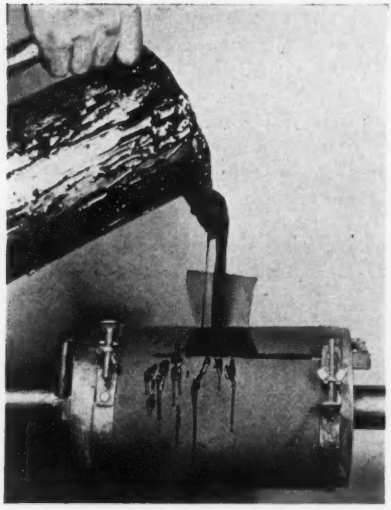


Figure 5—Pouring hot enamel into assembled coating pan.

the major gas companies in the United States and from rolling mills which have the necessary equipment for applying protective pipe coatings. Intimate contact and co-operation, which is most desirable, is therefore not possible. Further, there have not been as yet any firms, located within a reasonable distance of our plants, catering to the application of pipe coatings. For these reasons it was therefore necessary for us to develop our own apparatus and technique for applying the type of coatings used in this territory.

All pipe, after being treated by pickling in an acid bath and a neutralizing agent, is shipped bare from the mill. In transit the pipe has time to weather and upon arrival at its

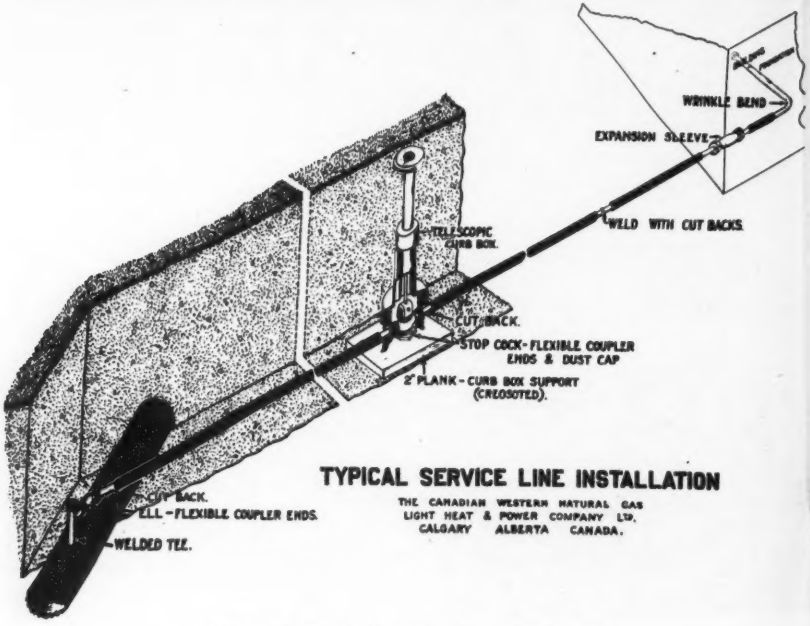

WRINKLE BEND
EXPANSION SLEEVE
WELD WITH CUT BACKS
TELESCOPIC CURB BOX.
CUT BACK.
STOP COCK-FLEXIBLE COUPLER ENDS & DUST CAP
2" PLANK-CURB BOX SUPPORT (CREOSOTED).
TYPICAL SERVICE LINE INSTALLATION
THE CANADIAN WESTERN NATURAL GAS LIGHT HEAT & POWER COMPANY LTD. CALGARY ALBERTA CANADA.
BACK.
ELL-FLEXIBLE COUPLER ENDS.
WELDED TEE.

Figure 6—Typical service line installation.

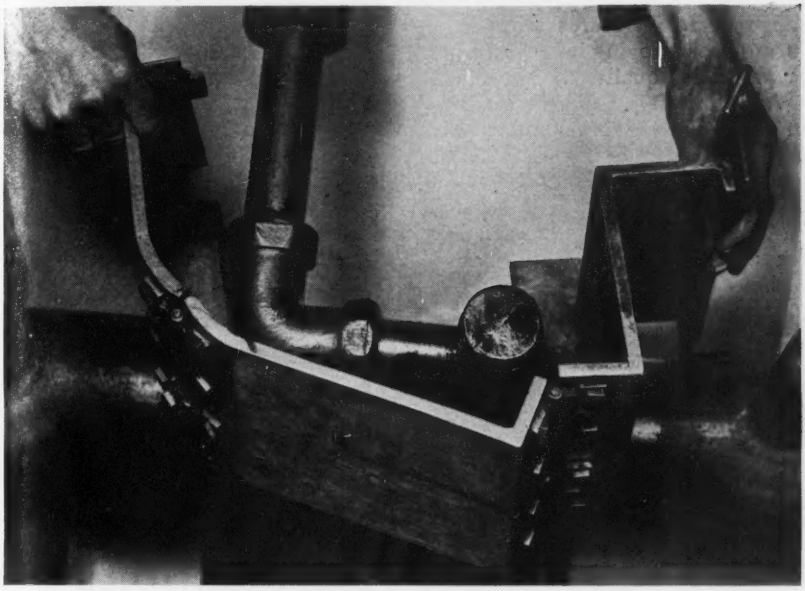


Figure 7—Assembling cast aluminum enameling pan around service connection.

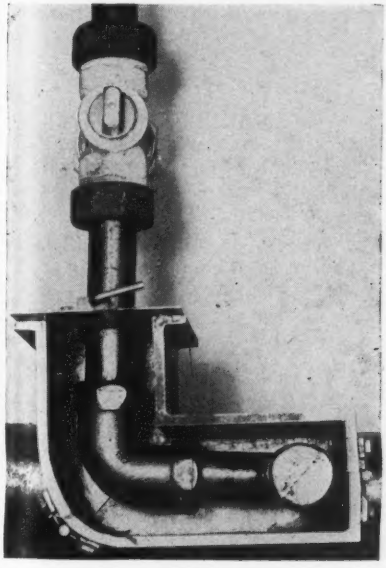


Figure 8—Cast aluminum pan in place.

destination it is covered with a light red rust which is readily removed by mechanical cleaners, leaving a clean, smooth surface over which is immediately applied, at the proper temperature, a thin bituminous primer. There are more scientific and possibly more efficient methods of coating pipe but it was found most economical and advantageous in our territory to clean, prime and then enamel all pipe from 1 inch to 6 inches in diameter in a central yard by the dipping process. On account of the pipe having to be handled, stored and hauled to the job as required, a hard semi-pliable coating, impervious to moisture, known to the trade as Waterworks Enamel, is used for the purpose. This particular product, if properly applied, will withstand flexing through a wide

range of temperatures without injuring or destroying its effectiveness or protective qualities.

After priming, the pipe is dipped in a trough containing hot enamel, the temperature of which is thermostatically controlled. For handling the pipe a special cup with a handle is fitted over the ends of each joint for a distance of 9 inches to 12 inches. This serves a two-fold purpose: First, to keep the enamel from entering the inside of the pipe, and second, to provide a bare section at the end of each joint of pipe to allow for acetylene or electric field welding. These bare sections or cut-backs are treated on the job, as will be described later. The enamelled pipe is electrically tested or "jeeped" to detect imperfections or holidays in the coating, and then spirally wrapped with a tar-saturated asbestos felt on a specially designed automatic machine, which we have developed to eliminate inefficient hand wrapping.

However, as simple as this may appear, each operation must be carried out with the utmost exactness, taking into consideration the human element and other factors involved. Naturally we have experienced failures. But over a period of time, with trained personnel, most of these have been eliminated.

I might mention at this point that we have given consideration to the installation of a stationary, automatically operated pipe-coating machine with a view to a possible reduction in labor and over-all cost. But so far we have been unable to purchase outright a suitable machine for this purpose.

Originally our operations were all carried out in the open where climatic conditions interfered considerably with results. So we found it was necessary to move all such operations under cover, where they

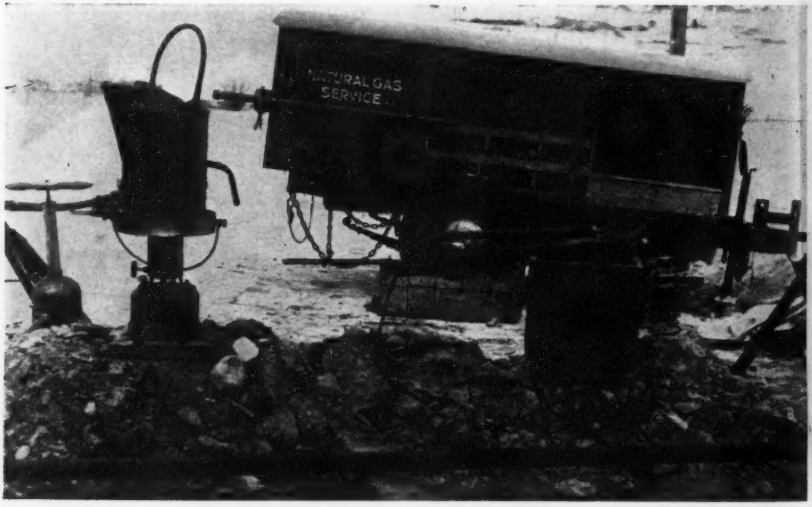


Figure 9—Melting pot (A). Holiday Detector (B).

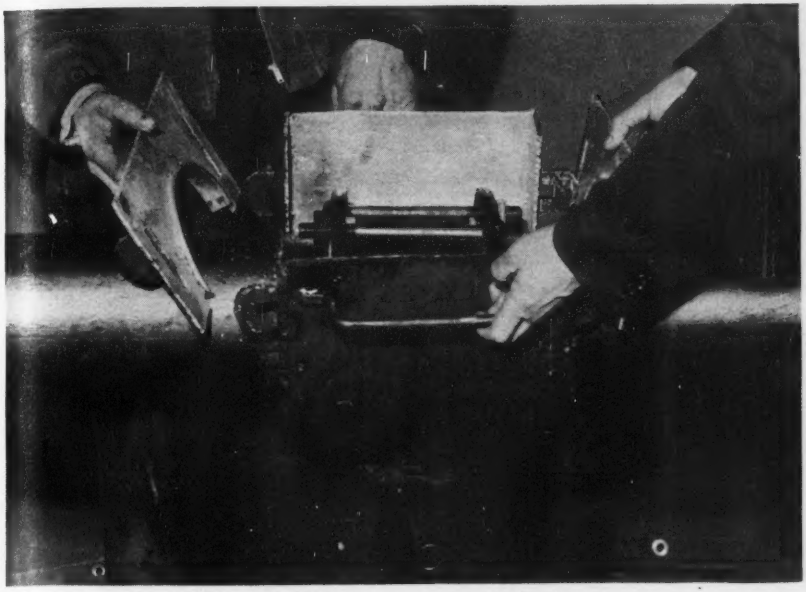


Figure 10—Pan developed for large couplings.

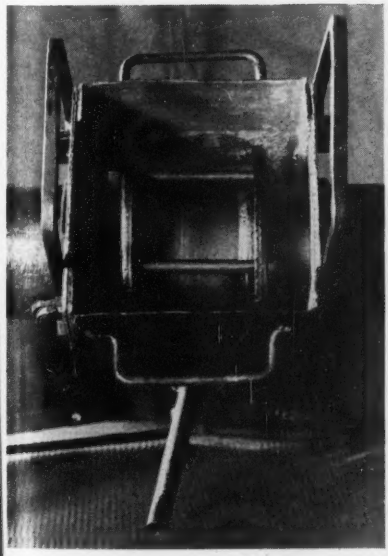


Figure 11—Large coupling pan in place.

can be carried on at will, regardless of changes in weather.

Pipe, up to a given diameter, is shipped from the storage yard to the job, coated and wrapped. After it has been assembled and welded over the trench, primer and enamel are immediately applied to the cut-backs. During cold weather the priming of these bare sections must be synchronized with welding and coating operations in the minimum of time. A quick-drying primer is used for the purpose, which usually allows the enamel to be applied within a 15-minute period.

The proper enameling of fittings, couplings and expansion sleeves has always been one of the weak points in a satisfactory coating job, and again it was necessary to develop special apparatus for the purpose.

For coating fittings on domestic service lines, where it is our custom to weld a steel tee to the main, onto which is attached a sleeve-type ell, a small compact light-weight cast aluminum coating pan is used, in which these fittings are completely immersed and coated in one operation.

For the coating of small expansion sleeves, sleeve-type couplings, etc., special pans have also been developed. All cut-backs and fittings on small diameter mains are coated by the sling method, using a strip of asbestos felt for the purpose.

A specially designed enamel heating kettle is standard equipment with every service tool cart. These kettles hold approximately two gallons of fluid enamel, which is ample for the coating of all the fittings and the cut-backs on each individual service line installed. All this field enameling is tested with a small portable electric "jeep" which is also included in the equipment of each service cart.

We have been dealing with high-melting point flexible enamel used both in the yard and in the field on small diameter pipe. But it is our custom to apply a product, known to the trade as standard pipe-line enamel, to all pipe of diameters greater than 6 inches. This coating is applied to the pipe over the trench, and pipe thus treated is buried as soon as possible after the application of the coating. Expansion joints and sleeve-type couplings on the larger diameter pipe are coated by using coating pans specially designed and developed for the purpose. The enamel used for coating these couplings is of the flexible or waterworks type.

For some years now the trend in pipelining has been toward all-welded construction. But for ease of installation and to provide for expansion and contraction, against settlement of other underground structures, and road shock, we considered it good engineering practice to install service lines with flexible-type fittings and sleeves as in one of the photographs.

The foregoing has dealt principally with coating installations in connection with small diameter service lines and short main extensions to existing distribution plants and is a recital of our own procedure and practice in dealing with a specific problem in a remote territory. It does not, of course, apply to any procedure followed in the construction of a large scale project where an entirely different technique would no doubt be employed.

In conclusion I can only emphasize that adequate protective measures against corrosion are of paramount importance in the installation of underground natural gas plants whether large or small.

Effective June 17th, 1946, all mail for N.A.C.E. addressed to Houston, Texas, should show the new office address: 905 Southern Standard Building, 711 Main Street, Houston 2, Texas. The telephone number is unchanged.

Meeting and Exhibition at Kansas City Set New Records for N. A. C. E.

STRIKING EVIDENCE of the importance of corrosion control was presented by the Annual Meeting and Exhibition held by the Association in Kansas City May 7th to 9th, with well over 500 registered for the meetings, and a still larger number reporting to the well-planned exhibits which characterized the first All-Corrosion Exhibition ever to be staged.

The meeting opened with a general session in the Little Theater of the Municipal Auditorium, with President R. A. Brannon officiating. After reviewing briefly the history of N. A. C. E., he outlined the work which must be done in combating corrosion, the extent of its inroads on industry, and the need for a collating and distributing center through which accumulated corrosion knowledge might be made available to all concerned with its problems. He said "N. A. C. E. offers to industrial societies and associations . . . the advantages of an Association devoted entirely to corrosion and covering the entire field. N. A. C. E. offers its fullest cooperation to scientific societies and associations which may be interested in the theoretical aspects of corrosion problems. Corrosion engineers

FRANCIS J. McELHATTON

Francis J. McElhatton, new President of NACE, is a native of Pennsylvania, Graduating from technical high school in Columbus, Ohio, he was employed by the Ohio Fuel Gas Company. Later he attended Ohio State University, majoring in electrical engineering and also receiving a degree in mechanical engineering.

He was associated with the Ohio Fuel Gas Company for 10 years, part of that time being field supervisor on the construction of compressor stations, gasoline plants, and pipelines. During this period he first became interested in corrosion control in pipelines.

In 1936 he accepted a position with Panhandle-Eastern Pipe Line Company. Later he was placed in charge of the Cathodic and Communication Departments and has since devoted the major part of his time to corrosion studies.

The new NACE president was for two years vice-chairman of the cathodic section of the Petroleum Industry Electrical Association. He is also a member of the Electrochemical Society. His efforts helped pioneer the NACE. His election to the presidency comes as recognition of his ability as a corrosion engineer and his ever-present willingness to cooperate in every way to promote the Association.

are primarily interested in the application of measures for corrosion control, but they also need a full understanding of corrosion.

"It seems that there is no conflict of aims or purposes between N. A. C. E. and any existing organization, but rather there is an opportunity for cooperative action which can result in great benefit to science and industry. I am confident that through our cooperative effort this benefit can be achieved."

Following the president's address, Dr. S. J. Rosch, Director of Research and Development, Anaconda Wire & Cable Company, gave a talk on the subject, "Romantic Views of Corrosion." He, in turn, was followed by Prof. F. A. Rohrman, Department of Chemical Engineering, Kansas State College, who talked on "Economic Aspects of Corrosion Problems."

Dr. Frank H. Trimble, Chairman of the Physics Department, Midwest Research Institute, briefly described the work of the Institute.

General Business Meeting

Following introduction of the Executive Secretary, Elton Sterrett, and the Managing Editor of CORROSION, William J. Sagstetter, the Association's treasurer, O. C. Mudd, reported on the financial condition of the organization from the time of its founding to the end of the calendar year 1945. He also added a supplemental report which covered the affairs of the Association to the close of March, 1946, indicating that N. A. C. E. had a cash reserve of over ten thousand dollars, exclusive of Convention registration income, but including initial payments on booths contracted for at the Exhibition.

The Executive Secretary's report covered the growth of membership in N. A. C. E., which stood at 641 active members, two junior mem-

G. R. OLSON

G. R. Olson, Vice-President of NACE, graduated from the University of Wisconsin in 1922 with a degree in Electrical Engineering. He joined the staff of the Utah Power & Light Company and remained with that company for seven years.

From 1929-34 he was with the electrical consulting division of Electric Bond & Share. In 1934 he was transferred to client companies in Bombay, India. Until 1939 he was general superintendent of operation and construction on the interconnected high-voltage electric power system serving that area. In 1939 he was placed in charge of the corrosion department of the United Gas Pipe Line Company in Shreveport, Louisiana.

He has been deeply interested in NACE since he helped organize it in its early days. He brings with him to the new office a wealth of sound, practical background in dealing with corrosion problems.

bers, 26 corporate representatives, and six from the associate group.

M. C. Miller, Chairman of the Galvanic Anode Committee, briefly described the preliminary work of his committee, and outlined the activities now under way by that group. He gave plans for cooperation between his and similar committees of other organizations, and predicted that installations to a standard plan would be made early this summer, so that it might be possible to present initial results and findings at the 1947 Annual Meeting.

George B. McComb, Chairman of the Regional Management Committee, outlined the plans of the Association for the establishment of five Regions, and, under this setup, to provide for local groups of Corrosion Engineers, in centers where grouping of industry brought together sufficient personnel to foster the formation of such groups.

Water Industry Symposium

The first Technical Sessions were held on Wednesday, May 8th. The Water Industry Symposium, H. Arthur Price, Chairman, was held in the East Concourse. The meeting opened with brief remarks by the Chairman, after which he read his paper "Corrosion in the Water Industry." He described some of the problems arising in his department, outlining in order problems of water meter corrosion, cavitation, and graphitization. He also described the operation of the electrolysis section and the handling of consumer complaints when they related to corrosion problems. (The paper appears in full in this number of CORROSION.)

L. P. Sudrabin read a paper, "Cathodic Protection as a Corrosion Control Method Applied to Steel Surfaces Submerged in Water," in which he traced the use of cathodic protection to structures of various types, drawing the conclusion that "protective current density require-

O. C. MUDD

O. C. Mudd has been Treasurer of NACE since the founding of the organization. He spent his boyhood days in Montana, attending Montana State College as an electrical engineering student. World War I interrupted his education. He served from 1917-19 in the armed forces, serving overseas in France.

After the war, he was employed by the Montana Power Company at Billings in operation and construction departments. In 1925 he became a superintendent of construction work for a firm near St. Louis. Work involved municipal improvements, levee building, and highway grading. In 1928 he accepted a position with Shell Oil Company at its Wood River Refinery. He was transferred to the Shell Pipe Line Corporation in 1933 to assist in the first organized corrosion investigation on its system. He has continued in this work and is now Senior Corrosion Engineer for Shell at Houston.

ments can be rationalized from the proper interpretation of dissolved oxygen concentration and scale depositing tendencies of the water, nature of the surface coating, the effectiveness of a barrier layer, the velocity and temperature. Operating conditions which influence any of the factors must be interpreted properly in order to apply cathodic protection most effectively. Often surface coatings used in conjunction with cathodic protection will provide the most effective over-all corrosion control."

G. H. Garrett, speaking on the subject, "Designing Water Pipe for Long Life and High Carrying Capacity," described a number of pipe installations in various parts of the United States, dealing solely with large diameter lines. In concluding, he stated: "It is quite evident that steel water pipelines, properly coated with coal-tar enamel, will have long life and high carrying capacity. Economy may be gained with perfect safety by having the walls of these pipelines relatively thin. It has been demonstrated by usage that bad soils which may attack other types of pipe will not attack the coal-tar enamel coating on steel pipes. It is safe to conclude that long lines, such as the Texas oil line mentioned, can be protected against electrolysis by coal-tar enamel coating. Flow tests show that coal-tar enamel-lined pipe has the same carrying capacity after several years of service that it had when it was new. Because of this, it is evident that algae and other growths do not build up on coal-tar enamel surfaces as they have done on other types of pipe surfaces. Therefore, the high carrying capacity in coal-tar enamel-lined pipe remains permanent with age instead of diminishing. Because the surface of the enamel remains permanently smooth, enamel-lined pipe can be expected to have a carrying capacity equal to, or greater than, that of other types of smooth interior pipe."

F. T. Redman closed the symposium by speaking on the subject: "Corrosion Control in Cooling Water Systems and Service Lines." He discussed the subject of metaphosphates, with results drawn from experiments and tests run in his laboratory, outlining control which was gained over corrosive conditions in actual practice based on earlier test results.

Electrical and Communication Symposium

Raymond M. Waggoner, Chairman of the Electrical and Communication Symposium, called the first session to order in the Little Theater. He introduced the first speaker, W. S. Bonner, who read a paper entitled, "Cathodic Protection and Applications of Selenium Rectifiers." After tracing the development of this type of rectifier, the speaker described its operation and outlined uses for it in systems where it served as current source. The talk was illustrated with slides showing details of construction, and various operating and design curves.

Discussing the subject, "Corrosion in and Around Generating Stations," J. A. Keeth outlined many cases of corrosion which had come under his observation, together with corrective or preventive measures adopted to insure longer life to the equipment. (This paper appears in full in this issue of CORROSION.—Editor.)

Robert Pope presented a paper,

"The Attenuation of Drainage Effects on Long Uniform Structures," in which he developed calculations covering this phenomenon of communication systems. He was followed by B. J. Barmack, on the subject, "Corrosion As It Applies to Overhead Distribution Systems."

J. M. Standring presented a paper on "Cable Corrosion in Non-Stray Current Areas." (This paper has not yet been released for publication, but it is hoped that it will appear in a forthcoming number of CORROSION. —Editor.)

"Construction and Ratings of Copper Oxide Rectifiers" was the subject of the next paper, presented by L. W. Burton, in which the various characteristics of this type of rectifier were described in detail. Following discussion of the technical selection and use of these rectifiers, the author then presented data on methods of use in protecting pipeline systems.

E. J. Wood and W. L. Roush both discussed "Cathodic Protection Rectifiers," describing various types of rectifiers, their uses, and methods for employing them in pipeline systems, and outlining the operation and care of circuits employing them.

Chemical Industry Symposium

The Chemical Industry Symposium of the N. A. C. E. began with a paper by Everett C. Gosnell on "Clad Steel Processing Equipment for Chemical and Allied Industries." William J. Powers, who presented the paper, discussed the types of clad steels that are commercially available and illustrated their application in various installations.

In the next paper Dr. N. E. Berry proposed the theory that thermogalvanic effects may be responsible for "Corrosion by Aqueous Solutions in the Absence of Oxygen." Dr. Berry and his co-workers found that when two pieces of the same metal at different temperatures were in contact with a solution containing the metal ion and were also connected by an external circuit, one of the electrodes was corroded, and metal was deposited at the other. It was possible to predict from thermodynamic calculations the extent and direction of the corrosive tendencies.

R. B. Mears discussed the use of "Condenser Tubes of Aluminum Alloys." He pointed out the variations in the behavior of alloys of different composition, and illustrated the use of sheets of aluminum alloys clad with alloys having a different composition.

In his paper on "Permeability and Corrosion in Protective Coatings," Dr. D. F. Siddall considered protective coatings from the viewpoint of their polymeric structure. He outlined the types and causes of failure of protection and suggested possible modifications of the coatings and application techniques which might improve their performance.

The final paper in the symposium was presented by C. E. Ford who discussed the "Application of Carbon and Graphite to Resist Corrosion". He described the properties of carbon, graphite, and porous carbon and illustrated fabrication techniques and typical installations.

Gas Industry Symposium

Under the chairmanship of Guy Corfield, this session opened with P. D. Mellon who described the procedures of his Company in coating underground piping with coal-tar

enamel, including the method for protecting couplings and other unusual shapes by use of removable forms.

H. A. Robinson presented data from laboratory and field tests, indicating that for current densities in excess of about 40 milliamperes per square foot, electrical recoveries of 500-600 ampere-hours per pound of magnesium may be realized, when the anodes are installed in suitable backfill material. The paper was discussed by H. W. Wahlquist of New York.

Michael Curran, substituting for the published authors, described the manufacture, physical properties and application of fiberglas, stressing that its chief function in underground pipe coating is as a reinforcement rather than a wrapper.

In Wm. R. Schneider's absence, his paper was read by Chris Goldkamp of San Diego, California. The paper described and developed a method whereby long-line currents can be neutralized, and cathodic protection current requirements materially reduced, by inducing current flow in the pipeline and adjacent earth by direct connection to the pipeline. It was stated that this accomplishes a saving, in both installation and operating costs.

Wm. E. Huddleston described a situation where severe bacterial corrosion had been encountered, which was successfully combated by application of cathodic protection at a pipe-to-soil potential in excess of one volt.

General Industry Symposium

R. B. Mears, Chairman of the General Industry Symposium, called the session to order in the East Concourse at 9 a. m. on May 9th, introducing the first speaker, George W. Seagren, whose paper, "Effect of Paint on Galvanic Corrosion" appears in full in this issue of CORROSION. Mr. Seagren described the effect of various types of protecting coatings as observed under standardized test conditions. The paper is further literature on the tests at Kure Beach, N. C.

T. G. Hieronymus then read an open letter to manufacturers, under the title "Disadvantages of Dissimilar Metals in Equipment," citing from current technical literature descriptions of equipment failure in various industries which are traceable to juxtaposition of dissimilar metals—in effect setting the stage for electrolytic corrosion. A brief paper entitled "Effects of Plastics on Corrosion" was inserted in the program at this point. The speaker, Henry F. Baker, described the effect of any material which oxidizes and thereby gives off water-soluble fatty acids and water, setting up conditions which foster electrolytic action and rapid corrosion of the metal to which they have been applied.

D. R. Hiskey, in his paper "Maintenance of Oil-Field Equipment," described numerous failures of protective coatings applied to oil-field storage tanks, tracing the causes of failures and pointing out means whereby the trouble may be avoided in future preparation and protection of the surfaces.

R. A. Frye, co-author with H. D. Holler, read the paper "Corrosion Ratings for Metals and Alloys." The paper covers investigations to determine relative corrosibility of metals in common use in industry, with reference to "typical" atmos-

pheric environments. The ratings developed were set out for bare metals only, and thus afford a comparative basis upon which to evaluate protective coatings.

R. H. Brown, co-author with R. B. Mears of "Designing to Prevent Corrosion," read the paper, which pointed out many instances where design or fabrication introduced factors which actually fostered corrosion by setting up optimum conditions for its occurrence. The paper is illustrated throughout by examples showing the common — and often improper — method of doing certain jobs and the suggested improved method which would retard corrosion.

Oil Industry Symposium

Walter F. Rogers, Chairman of the Oil Industry Symposium, which met in the Little Theater, Thursday, May 9th, called the meeting to order at 9 a. m. He introduced the subject by stating that the symposium was more directly concerned with presenting as much data as was available with regard to the treatment of condensate well corrosion problems. B. B. Morton presented the first paper, entitled "Resistance of Some Nickel-Containing Alloys to Corrosion by West Texas Crudes."

Following this initial paper, the remaining seven on the symposium were directly related to the condensate well phase of corrosion problems. T. S. Bacon and Paul Menaul each read papers entitled "Down-the-Hole Treatment of Condensate Wells." E. C. Greco read a paper entitled "Laboratory Studies for Determination of Organic Acids as Related to Internal Corrosion of High-Pressure Condensate Wells." M. E. Holmberg presented a paper on the subject, "Metallurgical Phases of High-Pressure Corrosion Problems." R. V. Smith, one of the co-authors, read a paper, "Use of Sodium Chromate for Control of Corrosion in Gas Condensate Wells." Walter Rogers and Harry Waldrip each presented a portion of the paper "Results of Some Studies of the Condensate Well Problem;" and W. D. Yale closed the session with a paper covering a specific example of the general problem, "Prevention of Condensate Well Corrosion by Chemical Treatment in the Erath Field."

Symposium on Corrosion Activities of Technical Societies

The afternoon session on Thursday combined earlier dual sessions, with the entire group meeting under the chairmanship of F. L. LaQue.

This symposium, organized by the N. A. C. E., provided an opportunity for several technical societies to describe how they were set up to handle corrosion. It served as a guide to how the N. A. C. E. could best fit into the corrosion picture so as to avoid duplication of effort and encroachment on fields of special activity which other societies felt they should continue to handle rather than encourage the N. A. C. E. to take over the work. It also gave an opportunity for some groups to encourage the N. A. C. E. to concern itself with corrosion in their fields, since these societies were not well organized to deal with corrosion.

Without exception, these other societies welcomed N. A. C. E. into the field and promised their full cooperation in matters of joint interest. In the discussion that followed the presentation of the formal pa-

pers, some of the plans of the N. A. C. E. were outlined. These included:

1. A proposal to collect abstracts of papers on corrosion from several sources and consolidate them in an abstract section of the publication "CORROSION" to be published monthly.
2. A proposal to reprint in "CORROSION," either completely or in the form of extended abstracts, important papers appearing elsewhere.
3. The intention to cooperate with other societies in the organization of symposia on subjects of interest to many groups.

It was brought out that N. A. C. E. could provide a means whereby knowledge gained in combating corrosion in one industry would be made more immediately available to those concerned with similar problems in another industry. By facilitating exchange of information and by coordinating efforts in tackling problems of broad concern, the N. A. C. E. reasonably can be expected to favor a more rapid and more economical solution to many corrosion difficulties.

The organizations who participated in the symposium were:

Organization—Representative:
American Chemical Society, F. N. Speller.
American Coordinating Committee on Corrosion, G. H. Young and G. W. Seagren.
American Foundrymen's Association, J. T. MacKenzie.
American Gas Association, R. E. Hadley.
American Institute of Chemical Engineers, R. B. Mears.
American Petroleum Institute (Production Division.) H. H. Anderson.
American Society of Mechanical Engineers, S. Logan Kerr.
American Society Refrigerating Engineers, R. S. Taylor and N. E. Berry.
American Society for Testing Materials, C. S. Cole.
American Water Works Association, H. Lloyd Nelson.
Electrochemical Society, R. B. Mears.
National Research Council, F. N. Speller.
Society of Automotive Engineers, E. H. Dix and R. B. Mears.
Technical Association of the Pulp and Paper Industry, J. A. Lee and E. C. Fetter.

In addition to the scheduled technical sessions, the meeting staged two general attendance meals, a buffet supper on Tuesday, May 7th, and the Annual Banquet on May 8th. The speakers at these events, Dr. H. B. Hass of Purdue University at the buffet supper and Mr. H. Roe Bartle of Kansas City, each held his audience with a most excellent talk, presented in an interesting manner. Attendance at the buffet supper was 404, at the banquet 440.

Approximately 40 percent of the enrolled membership of N. A. C. E. attended the meeting, and 10 percent of that number also brought their wives to Kansas City. These, with non-member visitors and exhibitors' staffs, brought the total registration up to 512, of which number 53 were ladies. No admission cards nor paid registration was required for the exhibition, but during the last two days of the meeting 154 visitors signed attendance cards at the door to the main arena.

The Exhibition—the first All-Corrosion Exhibition to be staged by any organization—occupied a total of 53 10x10-foot booths on the arena floor, and showed the latest in equipment, materials and methods for combating corrosion. The exhibitors expressed themselves as being well pleased with the attendance.

Corrosion Abstracts

METAL FAILURE

Properties of Aluminum-Magnesium-Calcium Alloys. T. A. BADAEVA AND F. I. SHAMRAY, Izvest. Akad, Nauk U. S. S. R., **1944** (Tekhn.) 182 (In Russian); J. Inst. of Metals & Metall. Abs., **12,** 277 (1945) Sept.

Aluminum alloys containing magnesium less than 0.75 percent and calcium less than 0.36 percent can be rolled at room temperature. After annealing at 550° C. their ultimate tensile strength is 6-13 kg./sq. mm. and total elongation of 15-41 percent. They are harder than aluminum. Their resistance to corrosion in sea-water, whether under tension or unstressed, is similar to that of aluminum. The alloy with magnesium 0.65 and calcium 0.05 is recommended for cladding (by hot rolling). Duralumin sheets to increase their corrosion-resistance.

New Aluminum Alloys, Containing Small Amounts of Beryllium. R. H. HARRINGTON, Gen. Elect. Co., Trans. A.S.M., Preprint No. **12,** 1 (1945).

New heat treatable aluminum alloys containing copper and beryllium in a ratio of 7 to 1 and copper, beryllium and cobalt with cobalt and beryllium in a ratio of 6.5 to 1 are described. Good mechanical properties of both wrought and cast alloys are combined with high thermal stability and unusual resistance to oxidation. The alloy containing 3.8 percent copper, 0.2 percent beryllium, 21.3 percent cobalt and remainder aluminum is favored for all-around casting properties. Procedures for sand, centrifugal and precision castings are given.

The Constitution of the Aluminum Rich Aluminum-Chromium Alloys—Paper 1002. G. V. RAYNOR AND K. LITTLE, J. Inst. Metals, **71,** 481 (1945) Sept.

Photomicrographic methods were used to determine the solid-solubility curve for chromium in aluminum between the peritectic temperature and 350°C. $CrAl_7$ is the phase which enters into primary solid solution $-\gamma + \text{liq.} = \theta$. At ordinary temperatures the solubility of chromium in aluminum is negligible under equilibrium conditions.

A Contribution to the Problem of Stress-Corrosion of Aluminum-Magnesium Alloys. P. MENZEN, Metallwirtschaft, **21,** No. 35, 526 (1942); J. Inst. of Metals & Metall. Abs., **12,** 251 (1945) Aug.

The corrosion-resistance of aluminum alloys containing 9-10 percent magnesium depends on the degree of dispersion and distribution of the β-phase. By a suitable rolling and annealing treatment, a very fine and uniform distribution of this phase throughout the grains can be obtained.

Fatigue Failure of Aircraft Parts —Their Cause and Cure. D. M. DAVIS, Consolidated Vultee Aircraft Corp., Paper before Inst. of Aero. Sci., An. Mtg. Jan. 29, 1945; Autom.

& Avia. Ind. **92,** No. 9, 34 (1945) May 1.

The major factors limiting the life of parts subjected to repeated loading are stress concentration due to faulty design, internal stresses due to heat-treating or welding, the notch effects of surface conditions because of machining, deflection and vibration. Fatigue tests and their results are discussed, and photographs and graphs are shown. Fatigue tests on a steel outer wing attachment fitting of a basic trainer were made showing a need for redesigning. Trouble in the empennage fittings was remedied by adding flanges to stiffen the edge, and stabilizers with chromium-molybdenum steel fittings installed doubled the life of the part. Failure of pulley brackets in the control system was eliminated by putting the load more directly into the web of the fitting when filled strips are added, and bending of the flanges is reduced. Failure in the fitting attaching the landing gear to the wing was eliminated by adding a saw cut to the bolt hole to relieve the stress.

Preserving the Corrosion Resistance of Stainless Steel During Annealing or Heat Treatment. G. C. KIEFER, Allegheny-Ludlum Steel Corp., Corr. & Material Protection, **2,** No. 2, 10 (1945) May.

Generally, steels in the AISI 300 series (containing chromium and nickel) are used under severe corrosive conditions. To better understand the need for a clean surface on stainless steel, a brief discussion of their structures and why they resist corrosion is offered. Cleaning methods, surface conditioning, furnace conditions and annealing procedures are discussed and photographs are shown. Chromium-nickel types of the 300 series are apt to be affected by careless annealing to a greater degree than steels of the 400 series chromium. A table lists the response to heat treatment for the most widely used steels in the 300 and 400 series.

The A-B-C of Corrosion and Heat-Resisting Steels, Research Div. of Rustless Iron & Steel Corp., April 1945, Metal Progress, **47,** No. 5, 936-B (1945) May.

This is a table showing 3 groups: martensitic (straight chromium, hardenable); ferritic (straight chromium, non-hardenable); and austenitic (chromium-nickel, non-hardenable). For each group the following is discussed: type numbers, chemical analysis, heat treatment, toughness, structural changes at high temperatures, strength at elevated temperatures, hot working qualities, machinability, riveting, welding properties, corrosion resistance, and scaling resistance.

Free Oxygen Prevents Sulphur Attack from Hot Furnace Gases. J. H. G. MONYPENNY, Brown Bayley's Steel Works, Ltd., Metal Progress, **47,** No. 5, 933 (1945) May.

The belief that high nickel was detrimental to heat resisting steels exposed to sulfur in furnace gases was based on the fact that sulphurous gases could form a eutectic of nickel and nickel sulphide on the alloy surface melting at 1200°F. J. F. Kayser experimented with alloys containing 60 percent nickel or more, but it was assumed that a

similar effect would result with the austenitic chromium-nickel steels of lower nickel content. Austenitic chromium-nickel steels have desirable properties and continued observation showed that they were not so bad, the key of the situation being the amount of free oxygen in the sulphurous furnace gases. If these gases contained 3 or 4 percent oxygen a protective scale was formed, and even such a high nickel alloy as 25 percent chromium, 20 percent nickel could be used satisfactorily. Incomplete combustion produced a scale containing sulphide. Iron sulphides and chromium sulphides also form easily fusible eutectics.

Corrosion-Resistance of Chromized Carbon Steel Against Sulphur Compounds. V. I. ARKHAROV, G. N. KOLEANIKOV AND S. A. NEMNOVON, Zhur. Priklad, Khim., **16**, 405 (1943) (In Russian); J. Inst. of Metals & Metall. Abs., **12**, 218 (1945) July.

Carbon steel (0.3 carbon) treated with chromous chloride ($CrCl_2$) vapor until the protective coating is 50μ thick, is more corrosion-resistant in 10 and 20 percent sulfuric acid solution at room temperature and in sulphur vapor and in sulfur + carbon disulfide + carbon monoxide at 300-650°C., than are chromium steel (chromium 18.5), mild steel, chromium-nickel steel, or electrolytic chromium.

Comparative Effect of Carbon and Nitrogen on Intergranular Corrosion of 18-8 Stainless Steel. H. H. UHLIG, General Electric Co., Electrochem. Soc. Trans. **87**, (reprint 13), 141 (1945) Apr.

Nitrogen is not as important a factor in intergranular corrosion as carbon. Attack was studied in boiling 10% copper sulfate + 10% sulfuric acid solutions and in hot 15% by vol. nitric acid + 3% by vol. hydrofluoric acid. 0.2% Nitrogen 18-8 stainless which had been heat-treated at 700° C. showed maximum attack which is parallel to carbon 18-8. These results, although possibly explained by nitride precipitation, indicate a more comprehensive theory of intergranular corrosion than presented heretofore. A special austenitic steel composed of 18% Cr, 24% Ni, balance Fe, was prepared which contained only 0.003% C and 0.006% N which showed intergranular corrosion in $CuSO_4$—H_2SO_4 solution after being heat treated at 500° C. The mechanism of corrosion in this alloy and in 18-8 appears to involve grain boundary precipitation of a metallic phase.

Corrosion Resistance of the Stainless Steels. C. A. ZAPFFE, Metal Progress, **48**, No. 4, 693 (1945) Oct.

The theory of passivity, contribution of various alloying elements in stainless steel to its corrosion resistance, effect of condition and fabricated form on corrosion resistance, and resistance of individual types of stainless to specific corrosive agents, organic and inorganic, are presented in condensed, convenient form. Data on the reaction of individual stainless steels to 97 organic and inorganic corrosive agents, compiled from Chem. & Met.'s 11th Report on Materials of Constructions and F. Ritter's "Korrosionstabellen Metallischer Werkstoffe" are appended. The position of types of stainless steels in the electromotive system is reprint-

ed from Steel, and data on wrought and cast forms are tabulated. Effect of stabilizers, titanium and cadmium as well as of nickel, chromium, molybdenum and copper, is discussed. Graphs show: 1, comparison of corrosion rates of 18-8 in copper sulfate solution with and without stabilization by titanium; 2, relation of carbon in 18-8 to intergranular corrosion after max. sensitization; 3, effect of molybdenum on cast 19-9 unsensitized and sensitized alloy; 4, hardened and tempered type 420 in sulfuric acid solution containing ferric sulfate as an oxidizer; 5, relationship between chromium content and amount of oxidizing agent necessary to cause passivation; 6, effect of nickel in 15-chromium stainless on attack by agitated and aerated sea water, 5 percent sodium chloride solution and calcium 20 percent chloride solution; and 7, breakdown of passivity of type 316 under conditions of dynamic flow of sulfuric acid slurry.

Progress Report on Graphitization of Steam Lines. S. L. HOYT AND R. D. WILLIAMS, Battelle Memorial Inst., Paper before ASME Ann. Mtg., Graphitization of Piping Sess. Dec. 1, 1944, Welding J., **24,** No. 5, 274 (1945) May.

An explanation of graphitization with a discussion of conditions found in present lines and suggested cures, as well as preventive measures for new lines. Work at University and Industrial Laboratories and the E.E.I.-A.E.I.C. Program at Battelle Memorial Inst. shows that low-aluminum deoxidized steels are more resistant to graphitization. Carbon-molybdenum steels are more resistant than plain carbon steels. Microstructure in the heat-affected zone is significant. Graphitization starts at the temperature which promotes spheroidization (Ac_1). Fluctuing temperature is not necessary to graphitization. Welding conditions have a pronounced effect of graphitization and normalizing the welded joint eliminates sharp gradient. Although not conclusive, it is reported that a chromium-nickel-molybdenum cast steel showed no graphite after being heated 2200 hr. at 1100° F. One of the major objectives of the investigation is to develop a steel not susceptible to graphitization, however it may be welded. Photomicrographs show the limit of weld heat-affected zone in carbon steel specimens at various temperatures. Show few scattered graphite particles only.

Changes in Materials Subjected to Fatigue Stresses. A. KARIUS, E. GEROLD, AND E. H. SCHULZ, Archiv fur das Eisenhuttenwesen, **18,** 113 (1944) Nov.-Dec., Bull. of the Iron & Steel Inst., **1945,** No. 114, 43a, June.

The changes in the damping capacity and elastic modulus of six steels, brass and aluminum caused by fatigue stresses were investigated. The steels comprised two 0.06 carbon steels, two chromium-copper steels, a molybdenum steel and a 25-18 chromium-nickel steel. At the beginning of the fatigue test there is a marked increase in damping and a corresponding drop in the elastic modulus due mainly to cold-deformation and the internal stresses which are set up; as the strength of the material increases the rates of change in the above properties gradually decrease. A second drop in the elastic modulus occurs shortly before failure

in the fatigue test. The magnitude of the initial changes in the damping and elastic modulus depends upon the volume of the test-piece, whereas the changes which occur just before fracture are not dependent on the volume. In fatigue tests on notched bars the stresses are concentrated in a small volume of the material and the damping elastic modulus continues to change rapidly throughout the test. Cracks occurred in the notch surface early in the test; at stresses below the fatigue strength these penetrated rapidly to a depth up to 0.1 mm. but did not become deeper as the test proceeded. Although the damping is very sensitive to changes in fatigue stress, it is not suitable for setting up damage curves.

Stress Corrosion Cracking of Mild Steel. Part I, Corrosion Cracking and Precipitation Hardening. JAMES T. WABER AND HUGH J. MCDONALD, Ill. Inst. of Tech., Cor. and Material Protection **2**, No. 8, 13 (1945) Nov.

The first of a series of articles on this subject. The theory that stress corrosion is preceded by precipitation at grain boundaries is given support by showing its relation to boiler embrittlement and aging. Evidence is cited to show that precipitation is related to nitrogen and carbon and that the prevention of aging or stress corrosion depends upon the presence of elements which will combine with nitrogen and/or carbon. 101 references are cited.

Nature of Cavitation. J. K. VENNARD, Proceedings of the Am. Soc. of Civil Engrs., **71**, 1000 (1945) Sept., Corr. and Material Protection, **2**, No. 7, 23 (1945) Oct.

Summarizes the facts of cavitation which are pertinent to civil engineering problems and brings to the attention of the profession certain experiences with the phenomenon.

Experiences of the Bureau of Reclamation. J. E. WARNOCK, Proceedings of the Am. Soc. of Civil Engrs., **71**, 1041 (1945) Sept., Corr. and Material Protection, **2**, No. 7, 23 (1945) Oct.

With the trend to larger hydraulic structures, cavitation and the resultant pitting has become a major problem to the hydraulic designing engineer. Experience in the laboratory and in the field shows that prevention of cavitation is fundamentally a function of design.

Attack of Zinc by Gypsum. H. LAFUMA, Inst. Tech. Batiment Trav. Publ., Circ. Ser. M, No. 8, (1943); Chem. Zentr., **114**, No. 2, 70 (1943); J. Inst. of Metals & Metall. Abs. **12**, 324 (1945) Oct.

Corrosion of zinc by gypsum is primarily due to contamination of the metal with lead, moisture content of the gypsum and porosity of the interposed paper layer. The use of purest zinc obtainable, paper impregnated with bitumen, and a dense, well-dried gypsum is recommended.

A Case of Embrittlement of Steel. Report by Nat. Bur. of Standards to WPB, Am. Electropl. Soc. Monthly Rev. **32**, No. 8, 784 (1945) Aug.

Failure by fracture of a zinc plated steel spring clip and zinc plated cylinder clamp for an oxygen breathing apparatus are reported. In the latter case, the clamp of carbon steel had been nickel plated formerly without

difficulty. Zinc plating brought a 40 percent loss during plating due to breakage. Reduction of number of spot welds from 6 to 4 reduced this to 10 percent. The only forming operation different for the zinc plated clips as compared to those nickel plated, is the plating operation. The cause of fracture is proposed to be absorption of atomic hydrogen during plating into tiny intercrystalline cracks formed during welding by absorption of molecular hydrogen in and near the spot welds. Formation of cracks took place in the clips during austenite-to-martensite transformation from rapid cooling after welding. It is possible that sound welds without martensite could be produced by pre-heating the clips to 600-700° F. prior to spot welding. Martensitic welds are not recommended in a spring. Microstructures are shown.

The Corrosion of Tin in Cooling Apparatus. A. IVANOVA AND A. FEDORCHENKO, Zhur. Khim. Prom. **18,** No. 15-16, 40 (1941), (In Russian), J. Inst. of Metals & Metall. Abs., **12,** 284 (1945) Sept.

In a copper apparatus for producing liquid nitrogen and hydrogen from coke gas, a coating of pure tin is undesirable, since when the apparatus is repeatedly warmed and cooled, conversion to grey tin and destruction of the surface can result. The use of an alloy of 50 percent tin and 50 percent lead avoids this difficulty.

MISCELLANEOUS

Chemically Stabilized Paper Capacitors. D. A. MCLEAN, Bell Labs., Bell Labs. Record **23,** No. 3, 65 (1945) Mar.

Anthraquinone has been used for several years to stabilize Western Electric capacitors impregnated with chlorinated naphthalene and chlorinated diphenyl. Stabilized capacitors have an accelerated life performance equivalent to that shown by unstabilized materials at 30° C. lower temperature. Corrosion of positive electrodes from unstabilized capacitors is shown. The stabilizer also maintains leakage current at low and relatively stable values.

PIPE LINE CORROSION

Soil Corrosion and Pipe Protection. T. H. GILBERT, Southern Calif. Gas. Co., Petr. Eng. **17,** 82 (1945) Nov.

A practical discussion of the various factors contributing to soil corrosion and its mitigation.

Galvanic Corrosiveness of Soil Waters. H. S. PHELPS AND F. KAHN, Elect. Eng'r. **64,** No. 4, 156 (1945) Apr.

Galvanic-cell tests were made using as electrolytes actual soil waters or soil extracts from 31 locations at which trouble had been experienced. The following conclusions were drawn: 1, galvanic corrosiveness on lead, copper and iron appears generally more severe for soil waters of low pH than for those of high pH; 2, the static potentials of lead and iron are practically constant in soil electrolytes of pH up to approximately ten; as pH is increased above ten, lead becomes more negative and iron more positive. The potential of copper becomes more negative in substantially straight-line relation with increasing pH. Carbon poten-

tials appear to be practically independent of pH of soil waters; and 3, for electrodes of lead, copper, iron, carbon in soil waters, the relation of degree of polarization to pH of electrolyte seems to show definite trends.

Welded Stainless Steel Tubing. Heating & Ventilating, **42,** 75 (1945) June; Metals Review, **18,** No. 7, 19 (1945) July.

Electric welded stainless steel tubing for pipe lines carrying active chemical solutions is discussed. Tubing is made by passing flat-rolled steel through a series of forming rolls which form it into a cylinder and press the edges into contact. Then heavy current flows through the metal, welding the seam and forming a solid wall without the addition of extraneous metal. The result is tubing with all the inherent advantages of flat-rolled stainless steel plus a weld as strong and corrosion resistant as the rest of the wall.

REFINERY CORROSION

Sulfide Corrosion Complicates Tank-Cleaning Operation in Tampico Refinery. FABIAN A. STALEY, Oil & Gas J. **44,** No. 34, 250 (1945) Dec. 29.

Crude oil storage tanks which contained parts of corroded tops which had fallen, rust, sand, water and oil were cleaned in preparation for repairing. Roof plates were removed as a safety measure, the manhole was opened and low viscosity fluid allowed to flow into pit. Viscous material was picked up by a steam jet vacuum arrangement and the viscous oil was heated by the steam so that it flowed freely. Tanks were completely clean at end of operation.

SURFACE TREATMENT

Corrosion Protection by Phosphatization — A Review. MICHAEL A. STREICHER, Syracuse University, Corrosion **1,** 219 (1945) Dec.

A review article with 43 references which discusses the chemistry of phosphatization, properties of phosphatizing solution, essentials of precleaning operations, and character of phosphate coat and its relation to the finished product. Brief reference is made to industrial application. Phosphatization provides an excellent bond between metal and paint.

Application of Chlorates as Oxidizers in Phosphating. F. ROSSTEUTSCHER, Korrosion und Metallschutz, **20,** No. 5, 165 (1944).

The reaction mechanism of chlorates added to phosphating baths as oxidizing agents is discussed. The advantages of such baths include: no break-in period; no special linings for tanks; very low and constant iron content of bath; ease of maintaining effectiveness of bath; thin, flexible coatings rapidly formed; low phosphoric acid consumption; suitability of coatings for cold drawing operations.

Influence of Composition, Surface Finish, and Preliminary Treatment of Iron and Steel on the Formation of Phosphate Coatings. L. SCHUSTER, Korrosion und Metallschutz, **19,** No. 10, 265 (1943).

The influence of composition, surface finish, and preliminary treatment of iron and steel upon the formation of phosphate coatings is reported in detail. Six alloy steels, including a chromium nickel steel, were studied. Surface treatments in-

cluded were pickling and cleaning, effect of organic and alkaline cleaners, oil films and films of impurities. Data on hot-rolled sheet of open hearth and basic Bessemer steel heat treated in three different ways are given.

Chemistry of Surface Cleaning. R. SANDERS, Rurco Products, Inc. Iron Age, **155,** No. 15, 62 (1945) Apr. 12.

Phenomena connected with surface cleaning are explained. These include wetting, emulsification, saponification, colloidal activity, solvent power, pH, buffer action, total alkalinity and acidity, and water conditioning.

Oxide Coatings on Metals. A. G. SAMARTSEV, Acad. Sci. U.S.S.R., Moscow, 170 (1944) (In Russian); J. Inst. of Metals & Metall. Abs., **12,** 284 (1945) Sept.

Investigations are described of: 1, the oxidation of steel in alkaline oxidizing solutions; 2, the oxidation (blackening) of copper and its alloys in alkaline oxidizing solutions; 3, the anodic oxidation of copper and its alloys in alkaline solutions; and 4, the anodic oxidation of aluminum and its alloys in sulphuric acid solutions. In each case, besides determining the composition of bath required and the operating conditions, the author studied the mechanism of the formation and growth of the oxide films and their properties. Recommendations for oxidizing copper, copper-plated and copper alloy articles and for anodic oxidation of aluminum and its alloys are given.

Anodic Treatment of Aluminum Gives Corrosion Resistance. W. L. MAUCHER, Gen. Electric Co. Am. Machinist, **89,** No. 13, 105 (1945) June 21.

Benefits of anodic treatment of aluminum (the chromic and sulfuric acid processes) together with corrosion and abrasion resistance and electrical characteristics of the coating are discussed.

Processing and Packaging Heavy Equipment and Spare Parts. W. D. BROOKING, R. G. LeTourneau Inc. Steel, **116,** No. 15, 133 (1945) Apr. 9.

Processing and packaging developments used in protection of heavy grading and earthmoving equipment are described. Apparatus for washing, rinsing, drying, and dipping machined parts in corrosion-preventive compound is shown. Rust inhibitors are discussed.

CORROSION TESTING

An Apparatus and Procedure for Stress-Corrosion Testing. W. D. ROBERTSON, Canad. J. Research, **23,** No. 4, 263 (1945), J. Inst. of Metals & Metall. Abs., **12,** 324 (1945) Oct.

The design and operation of a large-capacity, stress-corrosion testing apparatus of the alternate-immersion type for use in aluminum-alloy development research is described. The testing procedure was established by investigation of the important controllable experimental variables, of which the following are discussed: 1, specimen preparation by etching in sodium hydroxide solution, degreasing carbon tetrachloride and oxide stripping with phosphoric acid inhibited by potassium dichromate; 2, the shape of the specimen with reference to the effect of corrosion at edges as a source of

erratic variation; 3, the electrolyte concentration in both sodium chloride and hydrogen peroxide; 4, the ratio of specimen surface to volume of electrolyte. A statistical analysis is made of the established routine procedure, and the components of variation contributed by the material and the experimental procedure are separated and evaluated as a function of the magnitude of the corrosion. A table of typical results is given for four aluminum alloys in various electrolytes.

The Development and Present State of Stress-Corrosion Testing of Light Metals. P. BRENNER, Aluminium, **25**, No. 10, 346 (1943); J. Inst. of Metals & Metall. Abs., **12**, 322 (1945) Oct.

The development of methods for establishing the stress-corrosion behavior of light metals is reviewed and critically examined, with particular reference to the form of the specimens and methods of loading. A new type of specimen is proposed, which is loaded by a lever device in such a way that the load may be accurately determined, and is simpler to prepare than the usual for-shaped specimens. Experiments using such specimens on aluminum, zinc and magnesium alloys are described, and the results compared with those for other types of specimen. The reproducibility of the methods is discussed.

A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals. R. C. BRUMFIELD, Calif. Inst. Tech., A.S.T.M., Preprint **28**, 1 (1945).

The value of the sulfur print has been established for the study of crack distribution, profile shapes, depth of penetration, and the rate of crack growth. A similar procedure might facilitate study of the relative merits of materials, surface finishes, coatings and treatments in retarding crack growth and hence corrosion-fatigue damage. Equipment and procedure used by author in experiments are described.

Stress Comparisons by Corrosion with High-Frequency Magnetic and Eddy Current Losses. P. E. CAVANAGH, Allen B. DuMont Laboratories, Inc., Trans. A.S.M., Preprint No. 3, 27 (1945).

A high-frequency oscillator, whose output is governed by magnetic and eddy current losses, was used for the non-destructive determination of stresses in metals and alloys resulting from cold working and quenching, the beginning of plastic deformation, and the prediction of fatigue failure. Examples are given for high-carbon and low-carbon steels, Sten gun pins, aluminum, brass, 40-mm. tractor bodies and shot-peened springs. Limitations of the method are described.

Corrosion of Cast Zinc Alloys. E. K. T. B. TOE WATER, Schweiz, Ver. Gas u. Wasserfach. Monats. Bull. **22**, 128 (1942); J. Inst. of Metals & Metall. Abs., **12**, 324 (1945) Oct.

Corrosion tests were carried out by exposing the materials to saturated water vapor for 10 days at 95-100°C. Selective corrosion depends on a number of factors, among which are the presence of small amounts of lead which induce corrosion, aluminum content, etc.

Dutch specifications for zinc alloys prescribe 5 acceptable types having aluminum and copper contents 4 and 0, 4 and 1, 4 and 3, 7 and 4, and 0 and 4, respectively. The presence of aluminum improves the casting qualities; corrosion-resistance decreases with increasing copper content. The 7-4 alloy is the ternary eutectic and is not very corrosion-resistant. The 0-4 alloy is readily soldered. The presence of magnesium in small amounts will counteract the deleterious effects of lead, bismuth, tin, or cadmium. The total content of lead, tin, bismuth, cadmium and tellurium in the original zinc should be less than 0.12. Tin less than 0.001, iron-manganese less than 0.075.

The Corrosion of Magnesium and Its Alloys. G. GIRE AND F. FOUASSOU, Chim. et Ind., **45,** No. 3, 133 (1941); Chem. Zentr., **114,** No. 1, 1323 (1943); J. Inst. of Metals & Metall. Abst., **12,** 252 (1945) Aug.

The corrosion of magnesium and magnesium-rich alloys in sea water and in a 10 percent magnesium chloride solution was investigated. The attack is analyzed and changes in pH are discussed. The pH rises rapidly to a maximum in 6-10 hr. which permits avoidance of lengthy testing procedures involving weight loss, and permits determination of the nature and rapidity of corrosion of magnesium samples including those with protective coatings.

Marine Corrosion Testing. Station at Kure Beach, North Carolina, Corrosion 1, 178 (1945) Dec.

A brief description with pictures of the coöperative corrosion testing program carried out at Kure Beach, North Carolina, where producers and users of materials and coatings carried out testing under almost ideal test conditions.

Electropolishing of Steel for Microscopic Examination. S. R. PRANCE, General Motors Corp. Steel, **116,** No. 17, 106 (1945) Apr. 23.

The process of electrolytic polishing for microscopic examination of steel is described.

Erosion Tests of Cast Alloys in Sea Water. L. R. VOIGT (Inco), Inco Magazine, **19,** No. 4, 9 (1945).

Tests were conducted to see whether cast Monel is more durable than bronze in swiftly flowing sea water. Both regular and "S" Monel specimens were used, the quantitative difference in attack of Monel and bronze was sought, and tests were conducted without the galvanic protection which existed in the practical situation which led to the tests (the successful salvaging of bronze impellers and repair shoes in salt water pumps by means of cast Monel shoes). Specimens were submerged on a disc which rotated at 200 rpm. (See **Corrosion 1,** 184 (1945) Dec.) Numerical data are given on corrosion loss at various locations on the disc, that is, rotating at different speeds. Comparative data on performance of M and G bronzes tested with the same apparatus are also given. Results confirmed the fact that resistance to erosion or impingement attack by sea water at high velocity is not a simple function of hardness, but that the effect of composition of the material on nature and protective value

of corrosion product films is more important. The tests proved that solid Monel impellers would withstand erosion without galvanic protection and are superior to bronze. "S" Monel was attacked slightly more than the regular composition, but its corrosion and erosion resistance is still excellent.

Spot Identification of Stainless Steels. H. W. MILLER, Carpenter Steel Co., Metals & Alloys, **21,** No. 5, 1364 (1945) May.

Methods for spot identification of stainless steels are outlined. It includes nitric acid, magnet (18-8 steels are non-magnetic in annealed condition but become slightly magnetic when cold-worked), spark, hardness, muriatic acid, sulfur spot, nickel spot and stabilization tests. A chart shows these tests, while a table analyzes the chemical composition of various types of steel, showing nickel content.

Rust Preventives. Steel, **116,** No. 14, 106 (1945) Apr. 2.

A comprehensive discussion of rust-preventing compounds and their selection, based on research at the E. F. Houghton and Co. Salt spray, high humidity and simulative weather tests are described. Rust preventives combining protective and lubricating qualities are listed. A formula for producing synthetic perspiration is given. The order of increasing difficulty in obtaining continuous protective coatings on complicated surfaces from the four main types of protective compounds is: 1, the stripable plastic type; 2, heavy oil or grease type; and 3, oil types. Solvent selection and application are discussed.

Corrosion Tests of Gear Lubes—Their Significance. W. L. NELSON, Oil & Gas J., **43,** No. 48, 97 (1945) Apr. 7.

An explanation is asked for use of lubricating oil which is non-corrosive at ordinary temperatures but corrosive at elevated temperatures. Lubricating oil should not be corrosive at ordinary temperatures for the protection of the gear housing, box, etc. The corrosive additive acts as an automatic agent for smoothing or grinding the surfaces to whatever degree of smoothness or contact surface may be required to carry the load. Shock tests for automotive gears are described. Dibenzyl disulphide gear-lube additive, corrosive to copper at 300°F. and non-corrosive at 212° is used for small hypoid gears now employed in automobile transmissions.

Corrosion Test Strips. Business Week, **1945,** No. 840, 66, Oct. 20.

Lead plated on thin strips of copper ¼-in. wide in 7 steps of different thicknesses from 3/1,000,000 in. to 100/1,000,000 in. constitutes the business part of the new Type C Bearing Corrosion Test Strips manufactured by Randall & Sons, 2512 Etna St., Berkeley 4, Calif., for the operators' truck, bus, and taxi fleets. Purpose is to determine the corrosivity of new or used engine oils on lead-copper bearings in advance of possible damage. Attach a strip to the dip-stick of a Diesel or gasoline engine and wait exactly one hour. If only two of the very thinnest plated steps have been eaten off in that time, the oil may be considered practically non-corrosive. If more steps have been destroyed, the oil

may be anything from mildly corrosive to very corrosive.

WATER CORROSION

Threshold Treatment of Water Systems. Corrosion Control and Scale Prevention with Glassy Phosphate. G. B. HATCH, Hall Laboratories, and OWEN RICE, Calgon, Inc., Ind. & Eng. Chem. **37,** 710 (1945) Aug.

The use of small quantities of glassy phosphate for inhibiting scale formation and iron precipitation is presented. The absorption characteristics of the glassy phosphate are discussed in relation to scale prevention and corrosion.

Discussion by J. A. Holmes, National Aluminate Corporation.

Threshold Treatment of Water. J. C. SKERRETT, Dominion Flowmeter Co., Ltd., Paper before Chem. Inst. of Canada, Toronto, March 13, 1945, Canad. Chem. & Process Inds., **29,** No. 4, 226 (1945) Apr.

Use of phosphate additions in threshold equilibrium treatment of corrosive water is discussed. Oxidation and corrosion of pipe lines is covered. In passing, mention is made of the possibility of plastic pipes where water is extremely corrosive. Graphs show the calcium bicarbonate concentration in treated and untreated water.

Corrosion Control in Potable Water Systems. R. ELIASSEN, W. W. and Sewerage **92,** 187 (1945) June.

A discussion and some conclusions drawn as the result of recent observations, studies, and field experiences at Army posts. Effects of temperature and dissolved oxygen are discussed. The roles of protective coatings applied mechanically and deposited from the water are indicated. The application of film inhibitors such as sodium silicate and polyphosphates or a combination of the two are discussed. Continuous proportional feeding of chemicals is an important factor. Design for test unit to provide frequent observations of state of protection is considered essential.

Corrosion of Galvanized Coatings and Zinc by Waters Containing Free Carbon Dioxide. L. KENWORTHY AND M. SMITH, Engineer **179,** 249 (1945) March 30.

An abstract with discussion of a paper presented at the 37th annual Institute of Metals held in London March 14, 1945. Paper deals with the role of free carbon dioxide in the premature failures in galvanized cold and hot water tanks. Results show that increase in free carbon dioxide content increases the attack in all cases. However, in conductivity water pitting was most severe at the lowest carbon dioxide tested. The zinc appears to protect the iron in cold water as long as any is present but severe attack was experienced with hot water when 50 to 80 percent of coating still remained.

Protection of Small Water Systems from Corrosion, WILLIAM STERICKER, Philadelphia Quartz Co. Ind. & Eng. Chem. **37,** 716 (1945) Aug.

Practical methods for feeding and using sodium silicate to inhibit corrosion in small systems such as hot water systems and laundries are discussed. The function of sodium sili-

cate as an inhibitor is considered to be dependent upon the migration of the negatively charged silicate particle to the anode where the charge is partially neutralized to produce a labile film. This film stifles the corrosion and reduces the area undergoing corrosion.

Discussion by Henry L. Shuldener, Water Service Laboratories, New York, N. Y.

Corrosion in Hot-Water Systems. A. H. ULLRICH, Proc. Ann Arkansas Water & Sewage Conf., **14**, 72 (1944); J. Inst. of Metals & Metall. Abs., **12**, 325 (1945) Oct.

A review of the theories of corrosion and a discussion of the factors which apply to the corrosion of iron. Corrosion of galvanized hot-water heaters and piping at Fort Smith was not affected by low dosages (1.0 p.p.m. or less) of Calgon. Phosphates such as Micromet give protection when used in large dosages. As a temporary expedient, the use of Micromet feeders on individual heaters is recommended.

Corrosion in Pipe-Lines and Fittings. R. A. COLLACOTT, Marine Eng., **68**, No. 815, 305 (1945); J. Inst. of Metals. & Metall. Abs., **12**, 325 (1945) Oct.

The origin of pipe corrosion is first considered with reference to the presence of dissimilar metals, slag inclusions, metal particles suspended in the fluid, joints, and electric currents. The effects of corrosion in pipe-lines resulting in structural deterioration from loss of surface metal and weakening of local parts and from the effect of the products of corrosion on the flow of fluids through the pipe, is then dealt with. Finally, the control of corrosion by: 1, making all joints, wherever possible, with a non-conducting jointing compound; 2, controlling the fluid acidity and density; 3, checking all filters for the presence of filings and other impurities; 4, and isolating the system from any electrical currents, is discussed.

Ferrous Piping Systems in Buildings. H. L. SHULDENER, Water Service Labs., Corr. & Material Protection, **2**, No. 2, 6 (1945) Aug.

Corrosion problems confronted where war restrictions led to the use of ferrous instead of copper or brass water pipes are discussed, with suggestions for design, maintenance and operation. Examples are given from a large hospital which was piped with black ferrous (ungalvanized) pipe, and problems encountered where both non-ferrous and ferrous pipings are used in the same system are discussed. Insulating couplings must be used between all dissimilar metal connections.

American Water Works Association Tentative Standard Specifications for Deep Wells. J. of the Am. Water Works Assoc., **37**, 913 (1945) Sept.; Corr. and Material Protection, **2**, No. 7, 23 (1945) Oct.

Deals with materials for casings and liners. Pipe linings are used for corrosion protection. Among the points to be considered in the selection of pipe is the corrosiveness of the water. Deals with materials for well screens, with special attention to corrosion resistance. Materials most commonly used in corrosive waters are Everdur metal, silicon bronze, Toncan iron, and Armco iron.

Scale and Corrosion Control in Potable Water Supplies at Army Posts. R. T. HANLON AND A. J. STEFFEN, Sixth Service Command, and G. A. ROHLICH AND L. H. KESSLER, War Dept., Washington, D. C., Ind. & Eng. Chem. **37,** 724 (1945) Aug.

When Army camps began springing up over the country a great many scaling and corrosive waters were encountered. An Army post was chosen for studying various methods of treating this water and the results were applied throughout the country. This paper reports: (1), that the control of scale can be accomplished economically by threshold treatment at temperatures below 180° F.; (2), the correction of corrosion difficulties, although not so pronounced as the control of scale-forming waters, has been accomplished by chemical conditioning. Method used in experimentation is described in detail.

Experience of the Tennessee Valley Authority. G. H. HICKOX, Proceedings of the Am. Soc. of Civil Engrs., **71,** 1057 (1945) Sept.; Corr. and Material Protection, **2,** No. 7, 23 (1945) Oct.

Describes caviation damage experienced by the Tennessee Valley Authority in the sluices of Norris Dam, the repairs made to the damaged areas, and the steps taken to prevent similar damage in other structures built by the Authority.

Corrosion of Well Pumps. T. E. LARSON AND J. B. WILLIS, J. Amer. Water Works Assoc., **36,** No. 8, 886 (1944); J. Inst. of Metals & Metall. Abs., **12,** 184 (1945) June.

Among known causes of corrosion in well pumps are stray currents, the use of dissimilar metals in unsuitable places, and the mineral content of the water. In general each pump installation should be considered as a separate study. Means of prevention are suggested; cathodic protection, chemical water treatment, bitumastic coatings, and careful selection of the metals used.

Some Cases of Corrosion in Engineering Practice. G. H. STANLEY, J. So. African Inst. Engrs., **42,** 135 (1944); J. of Am. Soc. Naval Engrs., **57,** No. 2, 304 (1945) May.

Methods used by the author for examining corrosion pitting on inner surfaces of oil cooler tubes and an analysis of causes of corrosion are discussed. Probing with a forked probe of spring steel wire helped in the location of pits and formation of ideas on their depth and extent. Examination of perforated tubes showed formation of extensive black (varnish) scale, whereas uncorroded tubes showed only a smooth olive-green patina. A comparison of corroded and non-corroded tubes and of corroded and non-corroded portions of the same tube showed clearly that corrosion was more liable to occur where surfaces had been rough originally, as a result of oxide scale removal subsequent to manufacture. The need is emphasized for greater care in complete removal of oxide scale during the pickling operation.

Zinc, Manganese, and Chromic Salts as Corrosion Inhibitors. R. S. THORNHILL, Cambridge University, Eng., Ind. & Eng. Chem. **37,** 706 (1945) Aug.

Data presented compare the rates of

corrosion of steel in various concentrations of zinc sulfate, manganese sulfate and various chromium salts in tap water solutions. Zinc and manganese salts were superior to chromium salts both in degree of protection and flexibility as to concentrations. Manganese salts proved less dangerous than either zinc or chromium. Discussion by W. H. J. Vernon and F. Wormwell, Dept. of Scientific and Ind. Research, Teddington, England. The failure of chromium salts to inhibit tap water corrosion to any extent is contrasted to the beneficial effect of chromates.

Galvanic Corrosion of Steel Coupled to Nickel—Effect of Chromate and Lime Additions to Water. H. R. COPSON, The International Nickel Co., Ind. & Eng. Chem. **37,** 721 (1945) Aug.

This investigation was started to determine extent of galvanic action between nickel and steel and to study methods of minimizing this attack. There was considerable galvanic action with a 3 to 1 area ratio of nickel to steel in Bayonne tap water. Sodium chromate plus rubbing successfully suppressed the galvanic action.

Chromate, Corrosion Inhibitors in Bimetallic Systems — Technology Under Conditions Encountered in Practice. MARC DARRIN, Mutual Chemical Co. of America, Ind. & Eng. Chem. **37,** 741 (1945) Aug.

Results of a five-year study of chromate corrosion inhibitors in bimetallic systems. The testing programs considered time of exposure, temperature, aeration, pH, and concentration of inhibitor. Discussion includes application in air conditioning, refrigerating brines, automobile systems, Diesel engines, etc.

Sodium Nitrite as Corrosion Inhibitor for Water. A. WACHTER, Steel Development Co., Ind. & Eng. Chem. **37,** 749 (1945) Aug.

Sodium nitrite, which has proven quite successful in inhibiting corrosion in gasoline pipe lines, may be used in brine solutions if sufficient chemical is used. The influence of pH on this system is discussed. Data given show inhibiting action of sodium nitrite on Admiralty brass, red brass, copper-nickel alloys and low carbon steel. The use of sodium nitrite in alcohol solutions is also proposed.

Corrosion Prevention by Controlled Calcium Carbonate Scale. SHEPPARD T. POWELL, H. E. BACON, AND J. R. LILL, Ind. & Eng. Chem. **37,** 842 (1945) Sept.

Studies of cooling-water corrosion in numerous war plants have shown that controlled calcium carbonate scale may be used under certain conditions to inhibit corrosion of steel equipment in water. The success of this treatment depends upon the conditions being such that a uniform scale will be deposited over the entire temperature range. Conditions under which this occurs are described.

How to Determine Conditions of Service for Condenser Tube Alloys. Elec. World **124,** 132 (1945) Aug. 4.

A chart is presented showing the manufacturers' recommendations as to the use of the various brass alloys in fresh water, salt water, steam condensate, water containing sulfur compounds, weak mineral acids and alkalis. Chart also indicates temperatures and velocities recommended for various alloys.

Engineering Aspects of Water Corrosion. Engineers' Soc. of West. Penn., 4th Ann. Water Confer., Corrosion & Material Protection, **2**, No. 1, 26 (1945) Apr.

Ten papers abstracted are:

R. Owen (Calgon, Inc.,), Corrosion Control with Calgon.

R. C. Adams (Naval Exp. Sta), Approval Testing of Naval Deaerating Feedwater Heaters.

A. W. Griffin (Wallace & Tiernan Co., Inc.), Conditions Leading to Anaerobic Corrosion.

L. F. Collins (Detroit Edison Co.), More Information Concerning Corrosion in Steam Heating Systems.

C. A. Bays and S. H. Folk (Illinois State Geol. Survey), Development in the Application of Geophysics to Ground-Water Problems.

A. C. Embshoff (Infilco), Operating Experiences with Accelerator Softeners and Clarifiers.

H. L. Beohner (Permutit Co.), Catalytic Lime Soda Softening by the Spiractor.

J. A. Holmes and C. Jacklin (Nat. Aluminate Corp.), Experimental Studies of Boiler Scale at 800 p.s.i.

F. N. Kemmer and J. Thompson (Cochrane Corp.), Some Characteristics of Acid Regenerated Carbonaceous Zeolite.

D. Miller (Permutit Co.), Latest Developments in Removal of Cations and Anions from Water by Demineralizing.

In tests of corrosion in steam return lines data showed that in the severe corrosion conditions set up, all of the copper alloys tested corroded at a rate less than one-half that of Bessemer steel; aluminum, tin, 18-8 stainless and Inconel showed practically no attack. Vent-condenser tubes of 80-20 copper nickel failed in 7 years.

Preventing Corrosion in Water-Disposal Systems. F. B. Plummer, The University of Texas, Oil & Gas J. **44**, No. 14, 123 (1945) Aug. 11.

Corrosion factors—oxygen, carbon dioxide, hydrogen sulfide, and electrolysis—are discussed. Coatings impervious to oxygen are suggested as remedy for oxygen corrosion. It is recommended that pH of acid waters be raised to from 7.5 to 8 to decrease acid corrosion. Coatings are recommended to reduce effect of both carbon dioxide and sulfur compounds. Use of dissimilar metals in construction is to be avoided.

Chromate Corrosion Inhibitors in Brine Systems. M. Darrin, Mutual Chemical Co. of Am. Paper before A.S.R.E. 31st Spring Mtg. Pittsburgh, Am. Soc. of Refrigerating Engrs. Corrosion Report, **1944** 21-27.

Laboratory trials with chromated brines were carried out to supply data on the relative effectiveness of different concentrations for retarding various types of corrosion in both aerated and quiescent brines. Results with calcium and sodium brines are presented in this report, for sufficiently long exposures to make comparisons of a number of conditions as they affected weight loss, bichromate consumption, pH change, panel and brine appearances, and corrosion scores. The principal data are for galvanized iron in calcium and sodium brines; some information is given for iron-aluminum and iron-brass in brines containing traces of free ammonia. Results are included for zinc chromate inhibitors.

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Corrosion of Steel by High-Temperature Steam. F. ALTON, Eng. & Boiler House Res. **58,** 209 (1944).

Recent investigations of the corrosive action of steam at 496-982° F. on various alloys employed in power plants are reviewed. Tables and graphs show the relation between loss in weight and composition of the metal at various steam temps. C. A. **39,** 3235 (1945).

The Reaction of Copper and Oxygen Saturated Ammonium Hydroxide. R. W. LANE, National Aluminate Corp. AND H. J. MCDONALD, Ill. Inst. of Tech., Corr. & Material Protection, **2,** No. 5, 17 (1945) Aug., and No. 6, 15 (1945) Sept.

To help solve the problem of corrosion of copper by ammonia, steam power plants using surface waters often containing nitrogenous matter as boiler feed water, experiments were conducted in the Illinois Inst. of Technonogy laboratory to supplement what is already known about the reaction of copper and oxygen saturated ammonium hydroxide. Information was sought particularly on the effect of linear velocity on the metal specimens and the concentration of ammonium hydroxide on the reaction. A review of previous conclusions is included. Full data from the new tests, including apparatus, graphs and tables of results, as well as conclusions are given. The overall reaction is best presented as a zero reaction largely controlled by diffusion. Theoretical equations are given to show thermodynamic and other relationships. Reaction rate was retarded by increased viscosity.

BOILER CORROSION

Detection and Prevention of Incipient Cracking in Firebox and Boiler Steel. R. MCBRIAN, Denver & Rio Grande Western R.R. Co., Paper before ASM Convention, "Metals for Railroads" Group Discussion, Metal Progress, **47,** No. 3, 524 (1945) Mar.

Brief discussion on aging of steel, fire cracking, corrugations, staybolts, rivets, inspection methods, and recommended locomotive construction practices, by the head of the Denver & Rio Grande Western Railroad Co. crack prevention department. Staybolt breakage had been greatly reduced by this company by use of molybdenum wrought iron. In four years no broken radial bolts have occurred where this has been used.

The Significance of the Silica-Sodium Hydroxide Ratio in Boiler Failure. CHARLES D. WEIR, James Watt Engineering Laboratories, Glasgow, Scotland, Mech. Eng. **67,** 834 (1945) Dec.

The author makes a mathematical analysis of data presented by Partridge and others on "Effect of Solution Composition on the Failure of Boiler Steel Under Static Stress at 250°C." He concludes that the silica-sodium hydroxide ratio cannot be regarded as having a significant influence on the susceptibility of boilers to intercrystalline cracking.

Carry-Over in Locomotive Boilers. A. WILLIAMS, Trans. ASME., **67, No.** 3, 197 (1945) Apr.

The major cause of carry-over in locomotive boilers is foaming. Evidence has been produced previously both for and against the theory that

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suspended solids increase foaming. The injurious effects of carry-over are described, particularly the wear of valve and cylinder bushings and packing, decrease of cylinder efficiency by the reduction in superheat, and failure of superheater units due to scale restriction. Proper control of feedwater treatment is discussed. Separation of carry-over from the steam and discharge of carry-over directly to the atmosphere may be accomplished by means of a suitable design of steam separator connected to an automatically controlled outside-discharge valve. Procedure and apparatus for testing forming solutions are shown and described.

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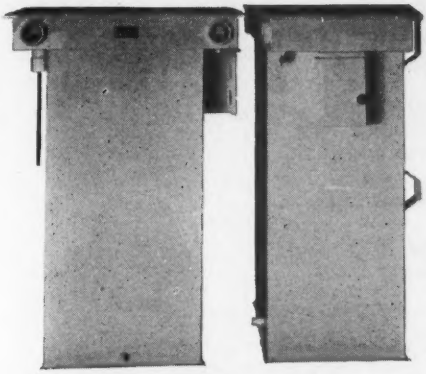

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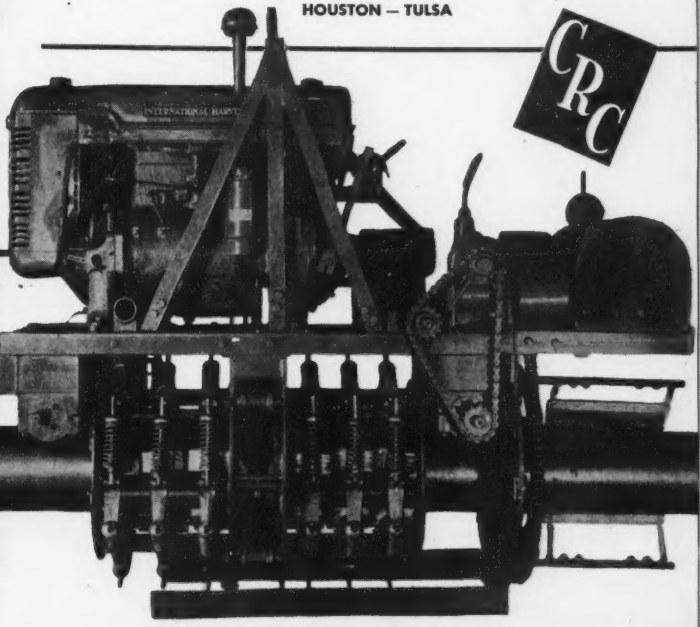

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